JOURNAL OF THE AMERICAN WELDING SOCIETY

VOLUME XI | SEPTEMBER 1932 | NUMBER 9

AMERICAN WELDING SOCIETY

PROGRAM

TWELFTH FALL MEETING

October 3-7, 1932

STATLER HOTEL BUFFALO, N. Y.

IMPORTANT NOTICE

Members and guests are requested to register immediately upon arrival, Mezzanine Floor, Hotel Statler, as admission to Exposition and participation in social events and inspection trips will be by badge only.

Upon registering you will be furnished with copy of the Journal containing papers to be presented at the technical sessions. The supply of Journals is limited, one to each registrant, and on this account you are urged to retain your copy throughout the meeting.

Morning technical sessions and committee meetings will be held at the Statler Hotel. Afternoon sessions at the 174th Regt. Armory, Buffalo, New York.

All sessions will start promptly as scheduled.

There will be no stenotype reporter. Members of the Society desiring to discuss papers are urgently requested to prepare their discussions in writing in advance of the meeting and to send copies to headquarters as those preparing written discussion will be given preference at the sessions. Members and guests giving extemporaneous discussion at meetings should forward a written transcript of their discussion as soon after the meeting as possible.

WELDING EXPOSITION

174th Regt. Armory, Buffalo

The Exposition will open at 12 noon on Monday.

It will open every day at noon and close at 10:30 P.M. every night except Thursday when it will close at 6:00 P.M.

Monday, October 3rd

Morning

REGISTRATION

Facilities will be provided throughout the week from 9:30 A.M. to 5:00 P.M., commencing Monday, October 3rd.

Afternoon

OPENING SESSION

1:45 P.M. Presiding Officer—G. W. Swan, President, The Engineering Society of Buffalo.

Address of welcome by local celebrity and response.

TECHNICAL SESSION

2:15 P.M. Presiding Officer—F. P. McKibben, President.

"Welded Rolled Steel Design for the Iron and Steel Industry," by Christian A. Wills, The William B. Pollock Company.

"Conditioning, Shaping and Machining of Carbon Steel with Oxygen," by H. H. Moss, The Linde Air Products Company.

"Oxy-Acetylene Cutting as Applied to Railroad Car and Locomotive Scrapping," by W. H. Ludington, Air Reduction Sales Company.

Evening

6:30 P.M. Dinner Meeting, Board of Directors, Statler Hotel.

Tuesday, October 4th

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—J. J. Crowe, Member, Board of Directors.

"Welding of Duralumin," by representative of Union Carbide & Carbon Research Laboratories.

"Welding of High Nickel Alloys," by J. G. Shoener and F. G. Flocke, International Nickel Co.

"Lead 'Burning' or Welding," by R. L. Ziegfeld, Lead Industries Association.

"Influence of a Magnetic Field Parallel to the Iron Arc on Welding," by F. R. Hensel and W. A. Maddox, Westinghouse Electric & Mfg. Company Research Labs.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—C. A. Adams, Director, American Bureau of Welding.

FUNDAMENTAL RESEARCH IN WELDING

"On the X-Ray Determination of Stresses in Welds," by John T. Norton, Mass. Institute of Technology.

"Metal Deposition in Electric Arc Welding," by G. E. Doan, Lehigh University, and J. M. Weed, General Electric Co.

"Corrosion Fatigue Study of Welded Low Carbon Steel," by W. E. Harvey and F. Jerome Whitney, Jr., Lehigh University.

"Distribution of Stresses in Welded Double Butt-Strap Joints," by S. C. Hollister and A. S. Gelman, Purdue University.

Evening

7:30 P.M. Statler Hotel. Conference and meeting of Fundamental Research Committee, American Bureau of Welding. H. M. Hobart, Chairman, presiding.

This conference is scheduled for the benefit of university research workers in the fundamentals of welding.

Wednesday, October 5th

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—J. B. Tinnon, Chairman, National Meetings and Papers Committee.

MERCHANDISING

"The Application of Welding to the Manufacture of Heavy Mechanical Equipment," by A. E. Gibson, Wellman Engineering Company.

"Selling Welded Products," by T. C. Fetherston, The Linde Air Products Company.

"Popularizing the Welded Product," by G. M. Gillen, G. M. Basford Company.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—J. C. Lincoln, Past Chairman, Cleveland Section.

"Pre-Qualification Tests for Welders," by E. Lunn, Chairman, Former Committee on Qualification of Welders.
Discussions of Mr. Lunn's paper by H. E. Rockefeller, Linde Air Products Company, and A. Vogel, General Electric Co.
"Qualification Requirements for Welders," by V. P. Marran, Walsh Holyoke Steam Boiler Works.
"The Chemistry of Low-Carbon Metal-Arc Weld Metals," by J. C. Hodge, Babcock and Wilcox Co.
Discussion of J. C. Hodge's paper by G. R. Brophy, General Electric Co.

Evening

6:30 P.M. Annual Banquet followed by dancing. Terrace Room, Statler Hotel. Tickets $4.50 each.

Thursday, October 6th

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—E. A. Doyle, Past President, American Welding Society.

"Load Test on a Welded Roof Truss," by C. H. Jennings, Westinghouse Elec. & Mfg. Co. Research Labs.
"Metal Spraying," by H. B. Rice, Metal Spray Company.
"Automobile Repair Welding," by A. F. Keogh, Sound Welding Company.
"Advantages of Thyratron Control for Resistance Welding," by W. C. Hutchins, General Electric Company.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—H. C. Boardman, Past Chairman, Chicago Section.

"Application of Welding to Pressure Vessels and Metallurgy of Welds," by P. R. Hawthorne and J. C. Holmberg, Struthers-Wells Company.
"Welding of Pressure Vessels," by H. L. R. Whitney, The M. W. Kellogg Company.
"Automatic Welding with Heavily Coated Electrodes," by L. R. Leveen, General Electric Company.

Friday, October 7th

Morning

Inspection Trip.

Authors of Fall Meeting Papers

GILBERT E. DOAN, co-author of the paper on "Metal Deposition in Electric Arc Welding," is Associate Professor of Physical Metallurgy at Lehigh University since 1926. Received his Ph.D. in Berlin University, Germany, and Ch.E. in Lehigh University. Developed testing of metals by radium's gamma rays, with R. F. Mehl and C. S. Barrett. Directs engineering foundation research in arc welding. Was Metallographist U. S. Naval Experiment Station and Director of Research of the Una Welding Company. Published: "Chemistry of the Carbon Arc"; "Energy of the Iron Arc"; "Welding with Pure Iron"; "Arc Not Obtained in Pure Argon"; "Testing Welds by Gamma Rays"; "Concerning Crater Formation," etc. Invitation lecturer Franklin Institute. Author of "Principles of Metallurgy" (in print), with Liddell.

A. E. GIBSON, author of the paper on "The Application of Welding to the Manufacture of Heavy Mechanical Equipment," is a graduate Mechanical Engineer of the Ohio State University. Was Apprentice, Night Superintendent, Superintendent and General Superintendent of The Wellman-Seaver-Morgan Company, also Works Manager. Was Vice-President and President of the Fulton Foundry and Machine Company. From 1929 to 1931 was Vice-President in charge of Works, of The Wellman Engineering Company (formerly The Wellman-Seaver-Morgan Co.). Since 1931 is Vice-President and Assistant General Manager in charge of Engineering and Works Production, of The Wellman Engineering Company.

WILBUR E. HARVEY, co-author of the paper on "Corrosion Fatigue Study of Welded Low-Carbon Steel," was born in Catasauqua, Pennsylvania, where he received his elementary and high school education. He graduated from Lehigh University in 1927 with the degree of Metallurgical Engineer. The following year Mr. Harvey was employed as Junior Engineer in the metals division of the Engineering Experiment Station at Annapolis, Md. In 1928 Mr. Harvey returned to Lehigh University as an Instructor in the Department of Metallurgical Engineering. In 1930 he graduated from the same institution with the degree of Master of Sciences, having specialized in metallurgy. Mr. Harvey is now Assistant Professor of Metallurgy at Lehigh University.

P. R. HAWTHORNE, co-author of the paper on "Application of Welding to Pressure Vessels and Metallurgy of Welds," is a member of the American Society of Mechanical Engineers and the AMERICAN WELDING SOCIETY. Formerly was Superintendent of the Heavy Welding Department of the A. O. Smith Corporation; also Welding Engineer of the Petroleum Iron Works Company. At present is connected with the Struthers-Wells Company of Warren, Pa.

F. R. HENSEL, co-author of the paper on "Influence of a Magnetic Field Parallel to the Iron Arc on Welding," studied for five years at the School of Mines in Freiberg, Germany, with Professor Dr. E. Maurer, Dean of the Metallurgical Department. For over one year Dr. Hensel worked at the Department of Applied Science in Sheffield, England, with Dr. C. H. Desch. In 1928–1929 he studied with Professor Dr. W. Guertler at the Technische Hochschule, Berlin. Since April 1929, he has been connected with the Research Laboratories of the Westinghouse Company and also with the Graduate School of the University of Pittsburgh.

JAMES C. HODGE, author of the paper on "The Chemistry of Low-Carbon Metal-Arc Weld Metals" is chief metallurgist of The Babcock & Wilcox Company. For the past six years he has been in charge of the technical development of welding for that company, and has been closely associated with the development and application of welding to boiler drums and pressure vessels. Graduated from Case School of Applied Science in 1923 and received the Doctor of Science degree from Harvard University, for work done during the last three years. The present paper is part of his thesis for the Doctor's degree and is to serve as the introduction to other papers on the properties of low-carbon metal-arc weld metals from subject matter of this theses, which will be later published from time to time.

J. C. HOLMBERG, co-author of the paper on "Application of Welding to Pressure Vessels and Metallurgy of Welds," was born in Oil City, Pennsylvania. His first job was in a steel plant of the Elyria Iron and Steel Co., in Cleveland in 1919. Went with Cyclops Steel Co., and was with Dr. C. T. Evans for four years. Became connected with the Titusville Forge Company, division of Struthers-Wells Titusville Corp., in 1929, as Metallurgist. Since then duties enlarged so as to embrace all divisions of the Corporation.

WARREN C. HUTCHINS, author of the paper on "Advantages of Thyratron Control for Resistance Welding," was born in Spartanburg, South Carolina. Is a graduate Mechanical Engineer with a degree of B.S. Attended the Clemson College of Clemson, South Carolina. Entered the employ of the General Electric Company in July 1928 and has had experience in the various engineering and commercial departments until Sept. 1931 when he became a member of the Welding Section. Has written a number of papers on various subjects, outstanding of which, is his study of the thyratron control when used in connection with resistance welding.

LAURENCE R. LEVEEN, author of the paper on "Automatic Welding with Heavily Coated Electrodes," received his degree in Mechanical Engineering from Washington State College in 1922. He was connected with the Lamb-Grays Harbor Company, at Hoquiam, Washington in their Engineering Department. In 1929 he joined the staff of the Manufacturing Methods Division of the Works Laboratory of the General Electric Company, at Schenectady. Since 1931, he has had charge of the Welding Engineering Department of the General Electric Company, at Schenectady.

(*Continued on page 38*)

On the X-Ray Determination of Stresses in Welds[1]

By JOHN T. NORTON

✦This paper will be presented at the Fall Meeting of the American Welding Society, in Buffalo, Oct. 4, 1932. Prof. Norton is Associate Professor, Department of Metallurgy, Massachusetts Institute of Technology.

ONE of the most important problems in welding deals with the question of internal stresses. The problem presents numerous difficulties because there is no simple and direct method whereby the "locked-up" stresses can be detected and measured, although there is abundant evidence of their existence in certain circumstances. It has been repeatedly suggested that the X-ray diffraction methods might be of use in this connection, and the purpose of this paper is to present a general view of the situation as it now exists and to point the way for further development.

In a previous paper,[2] the writer has described the "pinhole" or transmission method of using the diffraction of X-rays. This method employs a narrow beam of X-rays of a rather wide range of wave lengths, allowing the beam to pass through a thin layer of the material to be studied and fall upon a photographic plate or film placed beyond. The resulting picture is called a "pinhole" or transmission photogram. Another method employs "reflection" of the beam from the surface of a small specimen instead of transmission. With proper technique, these two methods give comparative results. These photograms are of great importance in supplying information about the grain size and grain orientation, and have been particularly successful in handling problems of cold worked metals.[3]

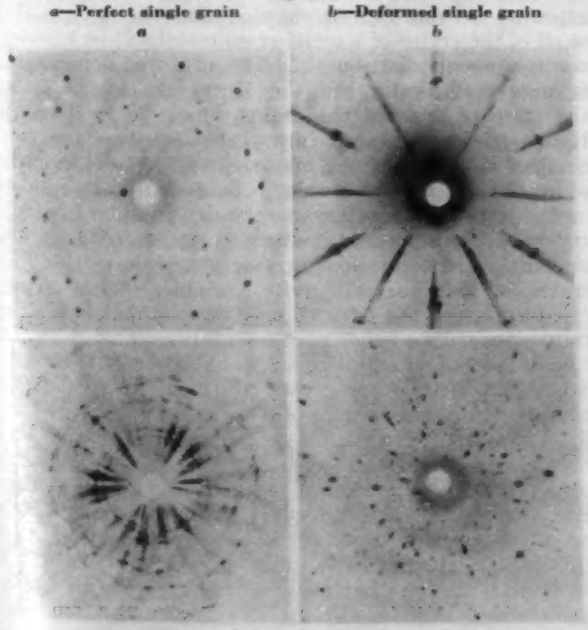


Fig. 1
a—Perfect single grain *b*—Deformed single grain

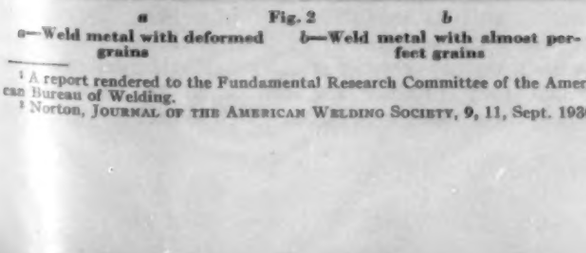


Fig. 2
a—Weld metal with deformed grains *b*—Weld metal with almost perfect grains

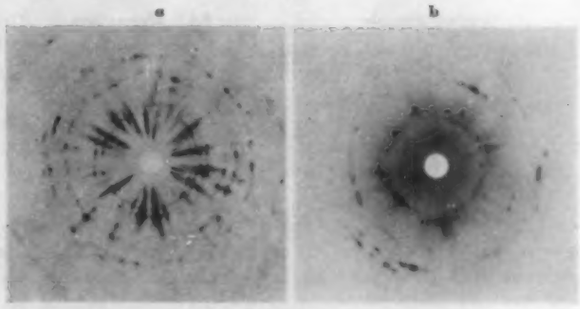


Fig. 3—Photograms of Weld Metal Showing Asterism
a—Without filter *b*—With filter
The same area of the same sample

Asterism

In addition to information about grain size and grain orientation, the transmission photogram is also indicative of the state of perfection of the grains themselves. This perfection is intimately connected with the present and previous history of the material in question. Compare the two photograms of Fig. 1, showing on the left a sample with a single perfect undeformed grain and on the right a single grain which has been severely deformed. The difference in appearance is striking and very characteristic. It will be noted that in the deformed sample each spot is elongated or drawn out into a streak in a general radial direction. This phenomenon has been called asterism. The appearance of asterism is not restricted to samples with large grains, but with very small grains the streaks become so numerous as to practically overlap and give the impression of only a general blackening of the background of the picture. Figure 2 shows two samples of metal deposited in welds, one indicating considerable grain deformation and the other almost none.

Meaning of Asterism

Quite regardless of any assumptions concerning the deformation process in a metal, the appearance of asterism has a certain definite significance. There are three variables which control the "reflection" or, more correctly, the diffraction of X-rays from a crystal grain and these are the wave lengths of the rays, the spacing of the atomic planes and the angle between planes and X-ray beam. It has been quite definitely proved that the spacing of the atomic planes in a metal cannot be changed except to a very small degree so that this may be eliminated from the list of variables. In order to obtain a photogram with sharp spots either the wave length or the incident angle must be a constant. Since sharp spots are obtained with a beam containing a wide range of wave lengths, it must mean that the atomic planes make a constant angle with the beam, that is, they are flat and truly plane. If asterism appears, it must mean that both wave length and angle are variables, that is, the atomic planes are not flat over the area illuminated by the beam. This may be corroborated by preparing a photogram of a sample which shows asterism, using a filter in the X-ray beam which reduces the range of wave lengths. The asterism is much reduced as Fig. 3 shows. In brief, then, asterism

[1] A report rendered to the Fundamental Research Committee of the American Bureau of Welding.

[2] Norton, JOURNAL OF THE AMERICAN WELDING SOCIETY, 9, 11, Sept. 1930.

[3] Norton and Warren, *Proc. Inst. Met. Div., A. I. M. E.*, 1927, p. 350; Norton and Hiller, *Tech. Pub. No. 448, A. I. M. E.*, 1932.

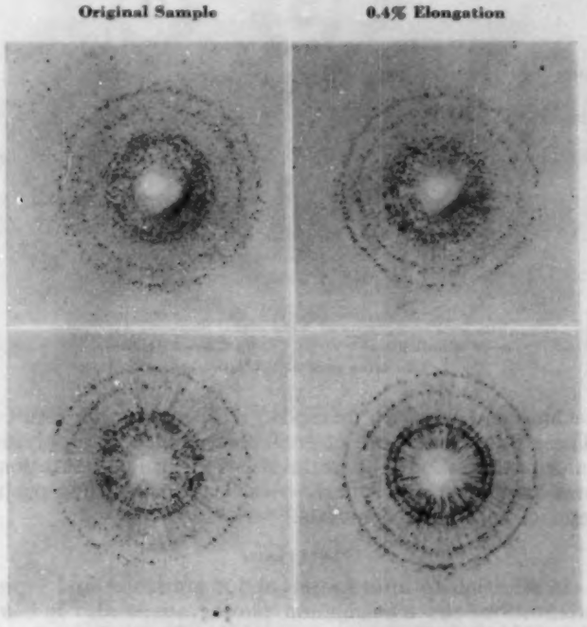


Fig. 4—Appearance of Asterism in a Sample of Aluminum Which Has Been Elongated in Tension by the Amounts Indicated

indicates that the planes of atoms in the crystal grains have been deformed.

Type of Deformation Indicated by Asterism

While much is known about the deformation of a single metal crystal under the action of external forces, the behavior of an aggregate of single crystals is still a matter of speculation. The application of stresses which have a magnitude less than the elastic limit of the material in question produces a distortion or deformation which is elastic in nature. If the stresses exceed the elastic limit, deformation of the crystal grain takes place by a process of slip or gliding on certain atomic planes and the stresses are somewhat relieved thereby. Obviously, in a crystal aggregate there may exist a whole range of internal stresses up to the elastic limit, and these stresses are accompanied by their corresponding elastic strains. In addition, the plastic deformation or fragmentation of the grain may be present if the applied stresses were large enough at any time.

The question then arises, is it the elastic strain which is responsible for asterism, or is it the plastic deformation? This question may be very definitely answered in the case of a soft material such as mild steel. One can calculate the range of angles necessary to give an observable radial streak on the photogram and can also estimate, in a general way, the amount of deformation needed to produce this range of angles. From any point of view, this distortion is of the order of several per cent and it is certain that the elastic deformation cannot exceed one-tenth of one per cent. Consequently, the elastic deformations in a metal cannot show as asterism. An actual sample, which is originally free from asterism, must be deformed by either tension or compression by several per cent before the asterism appears.

Some recent experiments[4] have shown that elastic "locked-up" stresses having a magnitude of 75 per cent of the elastic limit in the case of low-carbon steel cannot be detected by the appearance of asterism. In a material with a much higher elastic limit, asterism is shown with elastic deformation. This has been demonstrated by the use of a sheet of mica bent elastically. The conditions, however, are rather different from those found in metals.

Consequently, the asterism shown in the photogram of a sample of weld metal is due to a plastic deformation of the grains. There are two schools of thought as regard the type of deformation which is necessary to produce asterism. Simple slipping along cleavage planes is not sufficient because a marked rotation is necessary. One school inclines to the idea of bent crystals in which plastic bending takes place assisted by gliding so that there is no real fragmentation of the crystal. The other school believes that the deformation is a fragmentation process and that after deformation the grain is transformed into a series of small fragments each slightly displaced in angle from the next. Either picture would account, in a very general way, for the asterism and a careful analysis shows that the two points of view are really expressions of the same idea. It seems hardly profitable at present to pursue the question of the nature of the process much further because of our profound ignorance of the laws governing the deformation of crystal aggregates. It is better, perhaps, to consider the actual circumstances under which asterism appears.

Conditions of Appearance of Asterism

If a sample of metal be prepared by proper heat treatment so that the grains are so perfect as to show no asterism, and then be subjected to mechanical deformation such as tension, compression or torsion, asterism will appear when the deformation exceeds a certain amount.

The series of photograms of Fig. 4 indicate the appearance of asterism in a sample of annealed aluminum sheet which has been deformed by tension to the degree indicated. The photograms are of the same area of the same sample so that they may be directly compared. In this particular case, asterism makes its appearance at about one per cent elongation.

There seems to be no sharp lower limit of the amount of deformation detectable in this way, nor would it be expected for one cannot suppose that the deformation of all of the grains of a multi-grain metal will be homogeneous or evenly distributed. The measured deformation is an average value but the X-ray photogram shows the state of each of the grains which lie in its path. Hence, the appearance of asterism at two per cent elongation of a specimen may mean a local deformation of much more than this value. Some early experiments in the writer's laboratory on the deformation of single crystals of aluminum in tension indicated that the amount of deformation necessary to show the first traces of asterism was quite variable. With certain orientations of the crystal, primary slipping or gliding took place without change in orientation and a deformation of more than ten per cent could be obtained without asterism. With other crystal orientations very much smaller deformations were observable.

Deformation of metallic grains to a degree sufficient to show asterism can be brought about by methods other than the application of external forces. One of the commonest, though usually unintentional, methods of producing this condition is heat treatment. Under the proper circumstances grain growth can take place in such a fashion that some of the crystals are badly deformed. Also, conditions of uneven heating and cooling, such as are to be found in welding, are capable of producing this effect. In cases of this sort, there are unquestionably elastic stresses but the deformations which they produce are too small to show. Only where the stresses were large enough so that they required

[4] Experiments of Dr. D. L. Rosenthal in the author's laboratory. To be published shortly.

relief through deformation do we find asterism. Therefore, asterism indicates not where large stresses exist but where large stresses have been. But, whether the deforming stresses are applied from within or without, the nature of the deformation is the same and the same sort of X-ray evidence is obtained.

A common procedure for the removal of internal stresses in a welded structure is the stress-relief anneal. In this treatment, the metal is heated to a temperature below its recrystallization range (in the case of steel to about 550° C.). Under the circumstances, the ductility of the metal is much increased and one might ask if the X-ray photograms will indicate this effect. The answer must be in the negative. At room temperature only elastic stresses exist with magnitudes up to the elastic limit. Upon heating, the elastic limit is lowered and these stresses are able to relieve themselves by producing plastic deformation but the deformation thus produced is far too small to show as an increase in the asterism. Previous deformations, however, are unchanged by this treatment. Asterism can only be removed by raising to a temperature which will cause recrystallization and by allowing this recrystallization to take place in such a fashion that no further deformation is produced by the mutual interference of the grains during growth. Such a condition is not easy to obtain.

The photograms of Fig. 5 show the effect of heat treatment on a sample of low-carbon steel weld metal. Here again, the pictures are of the same identical spot of the same sample so that they are directly comparable. The heat treatment at 550° C. has made almost no change in the degree of deformation of the grains, yet the internal stresses have been largely relieved as is indicated by an increase in ductility of the weld itself of about 25 per cent. Heating to 900° C. has caused complete recrystallization and asterism has largely disappeared. The ductility is, of course, very greatly increased.

Practical Significance

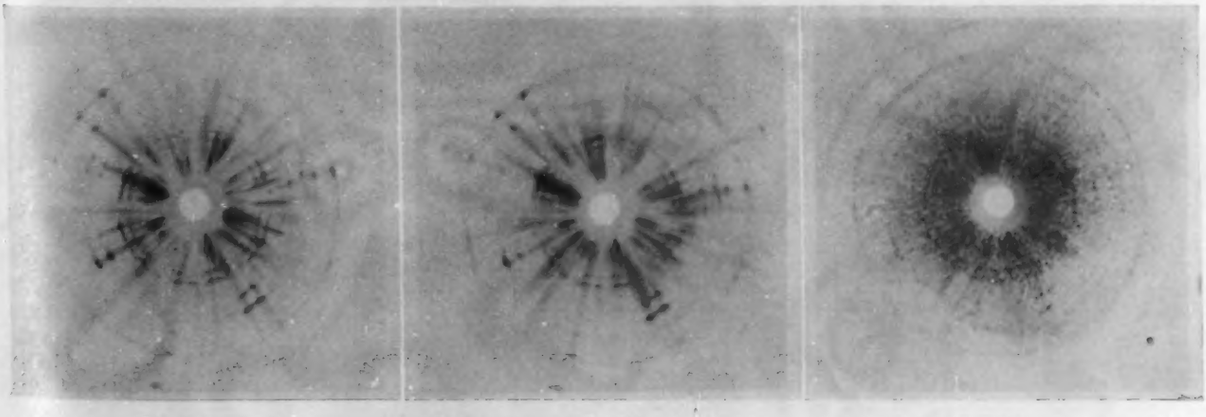
One must use a great deal of care in the interpretation of photograms showing asterism. The question of proper technique is of great importance for it is possible to be led completely astray without realizing it. Furthermore, the X-ray methods must be supplemented by the other well-established methods of metallography in order that the interpretation may be sound.

There is presented here the apparent paradox of a method of examination which is at once too sensitive and yet not sensitive enough. On the one hand, it is evident that the presence of elastic stresses with their corresponding strains cannot be detected and this is really the information which is most desired. On the other hand, there are so many secondary effects which are able to produce small amounts of plastic deformation that it is often difficult to decide on the real significance of the asterism. It is only by a careful comparison of the same material, or better, the same sample before and after treatment, that consistent and dependable results may be obtained.

It must be concluded from the foregoing that the state of stress in a metal sample cannot be directly deduced from an X-ray photogram taken in this manner. One might properly ask, therefore, of what use is this method of examination? The reply would be that the photograms supply very definite information about the amount of plastic deformation which individual grains have received by one process or another, and the extent to which this damage may have been repaired by recrystallization. With respect to the ductility of the sample, the perfection of the grains is not the only factor to be considered, but is a very important one. If the proper technique has been employed and a photogram showing no asterism is obtained, it may definitely be concluded that the sample has perfect grains and, other things being equal, that it has the maximum capacity for cold deformation. On the other hand, even though the appearance of asterism may be due to a variety of causes, its presence indicates just as definitely that the grains have been rendered imperfect by deformation and, consequently, their capacity for further deformation has been reduced.

Evidence is beginning to accumulate which seems to indicate that certain other physical properties of metals, in addition to the ductility, are dependent upon perfection of the grains. It seems very probable that many of the apparent inconsistencies, which have appeared in certain of the physical measurements made on metals, will be at least partly explained by taking into consideration these small local deformations. At the present time, the diffraction method is the only way in which such deformations can be detected or evaluated. The microscope does not show them until they have become very large. Results of mechanical, electrical and magnetic tests involve the influence of many factors which cannot easily be separated. In this X-ray method there is available a means of isolating and studying one particular property independently of the others.

In welding, the questions of impact resistance and fatigue resistance are of paramount importance. There can be no doubt but that these properties are profoundly influenced by the small local deformations of the grains, yet there have been no serious attempts to make a definite correlation.



Original Sample 550° C. 900° C.

Fig. 5—Effect of Heating on Asterism. The same area in each case

Welded Rolled Steel Design for the Iron and Steel Industry

By CHRISTIAN A. WILLS

✦This paper will be presented at the Fall Meeting of the American Welding Society, in Buffalo, Oct. 3, 1932. Mr. Wills is connected with the William B. Pollack Co.

THE tendency to favor welded rolled steel as a substitute for steel and iron castings is being recognized by a rapidly increasing number of engineers and manufacturers. The preference for such construction is attributed to many reasons.

The user obtains equal strength with less weight and is assured of the absence of porosity, shrinkage cracks and gas pockets often found in castings.

The rolled steel fabricator adds productive hours to his operations, is not penalized by the rejection of defective castings with the consequent loss of labor performed and delay in replacement, and avoids the cost of and responsibility for patterns, thereby securing a lower production cost.

Engineers are gradually recognizing the advantages to be obtained for both user and manufacturer by the use of welded rolled steel designs and are not only advocating their use in lieu of castings but are calling upon welded designs to replace designs of riveted rolled steel.

The adoption of welded rolled steel designs has been marked by short successive steps, many of which have guarded against failure by ingenuity in design, thus giving the weld an opportunity to prove its worth and safety—yet not depending entirely upon it. Actual tests and accumulated proof that such designs are safe and their adoption advantageous have created a growing interest in the art of welding and made it necessary for all manufacturers supplying equipment for the iron and steel industry to include consideration of this method of construction in their plans.

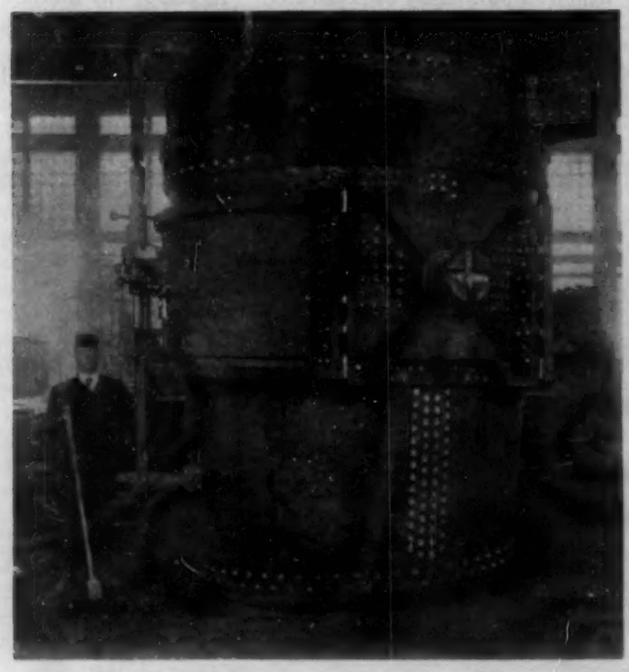


Fig. 1—Riveted Open-Hearth Ladle

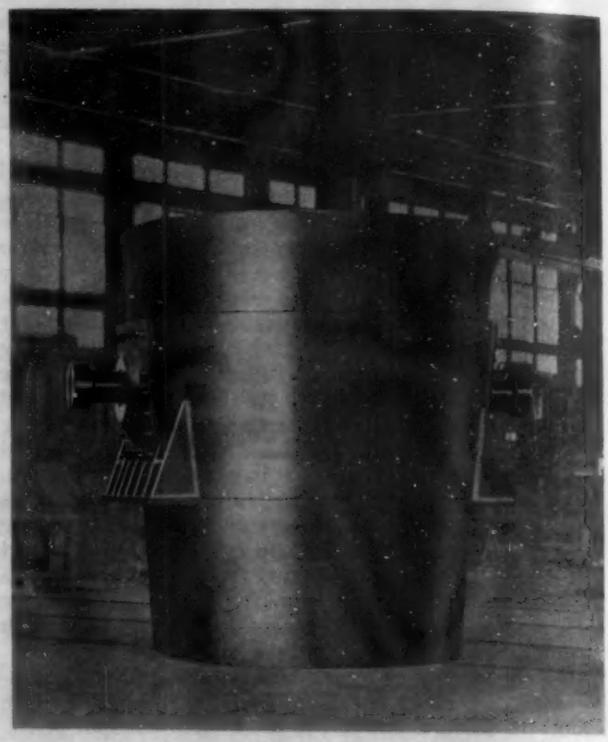


Fig. 2—Welded Open-Hearth Ladle

In reference to the adoption of such designs by the iron and steel industry, we would like to show some of the steps already taken and also what we are looking forward to in the matter of designs for this equipment. The records of our company, extending over a period of sixty-nine years, disclose many interesting natural developments of equipment for the manufacture of iron and steel by numerous engineers. Some engineers favor sturdy construction with an objective of long life, while others believe that improvements and advancements will soon make any design obsolete and offer equipment that will not be too enduring. The latter idea in many cases seems to have been the proper one, especially during the past few years when many blast furnaces have been remodeled and their production increased by 100%. Some people predict that the blast furnace fabricators will not build a new furnace for many a day, but grant that they may get a "cleaning and pressing job" on a furnace occasionally. In either case, the welded rolled steel design will play a prominent part.

To welding, however, must not be given all the credit for improvements in designs. Much has been made possible by the oxyacetylene torch without which welded products of heavy material could not be manufactured economically.

Imagine what this method of cutting material has meant to our industry when prior to its advent 2 in. was considered a heavy plate and it was necessary to make openings in hearth jackets and all such heavy construction by drilling or punching small adjoining holes and, after removal of the large piece, to chip with

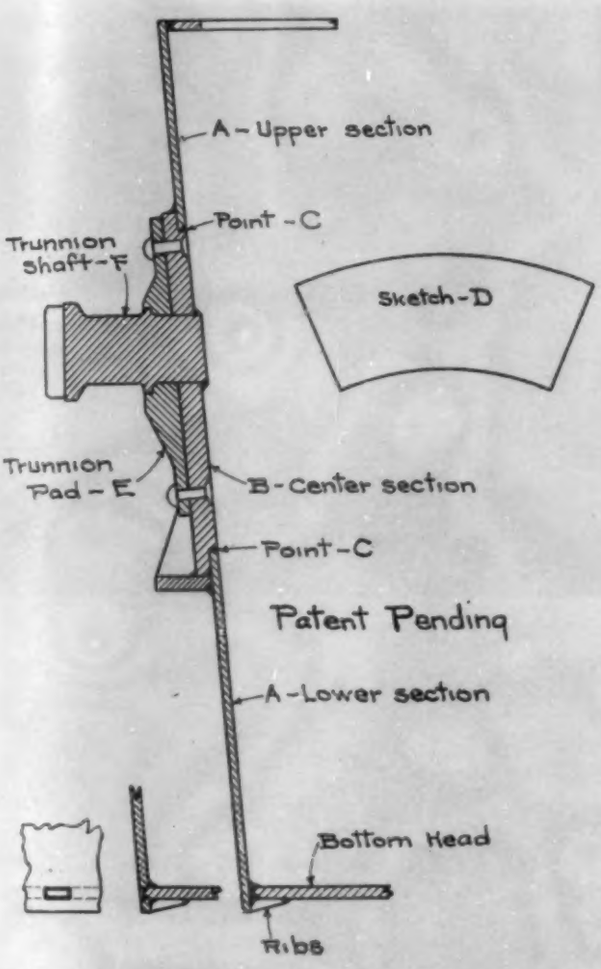


Fig. 3—Sketch of Welded Ladle

pneumatic tools the projections remaining between the holes. Such work, taking hours to do by that method, can now be done in minutes with the torch. Where 2 in. was considered heavy plate, now it is common to see 8-in., 10-in. and 12-in. slabs and billets being burned into pieces for fabrication by welding. Many machines have been developed that cut these thicknesses to curved or straight lines with surprising accuracy when operated by experts, and many ingenious devices have been invented in order to permit the use of the machine torch instead of one operated manually.

With the aid of such torches and the electric arc welding, we have produced welded rolled steel designs possessing decided improvements.

Consider the two open-hearth ladles in the Figs. 1 and 2. Both have a capacity of 85 tons of hot metal, yet the welded steel design weighs 21,000 lb. less than the riveted ladle with cast steel trunnions and spacers. In addition to the lighter weight and lower first cost, this welded rolled steel ladle will cost less to operate as the crane handling charges will be lower.

The welded ladle has the advantage of being perfectly smooth inside (Fig. 3) as the upper and lower sections (*A*) set in the heavier center section (*B*) which has been machined on the inside (at *C*) to receive the upper and lower sections. The central section (*B*) is $2^1/_2$ in. thick, was machine-cut to the required shape (*D*) with oxyacetylene apparatus, and afterwards rolled into cylindrical form.

Attention is called to the fact that the head has projections extending into the shell, and that, due to the taper of the vessel, it would be difficult to remove the lower section (*C*) from the central one (*B*) even though they were not welded solidly. These features were condidered and incorporated to insure safety.

In Fig. 4 notice the skill displayed in cutting with oxyacetylene the $6^1/_2$-in. slab from which the trunnion pad (*E*) was fabricated. The pieces in the vertical position were cut from the slab in roughing it out to the required shape. A circular groove was cut to a depth of 4 in., then these pieces were removed by burning into the groove. The slab was finished on a vertical boring mill and then formed with hydraulic presses to fit the curvature of the ladle shell.

The entire structure was stress-relieved at a temperature of 1200° F. before the $1^1/_2$-in. rivets were driven which secure the trunnion pad to the trunnion shell, as subjecting driven rivets to such a temperature would destroy their perfectness.

After riveting the pads to the ladle shell, the pad and shell were bored and the forged steel trunnion shafts (*F*) were forced into the trunnion pad and welded in position.

Compare the hot metal cars and ladles shown in Figs. 5 and 6. The cast steel riveted car and ladle weighs 190,000 lb. and has a capacity of 115 tons. The welded rolled steel has a capacity of 140 tons and with its tilting mechanism weighs 10,000 lb. less and carries 25 tons more hot metal than the cast steel design.

The welded side frame, or member connecting the end frames of the welded car, is made from two $4^1/_4$-in. x 10-in. slabs for top and bottom members with sides of

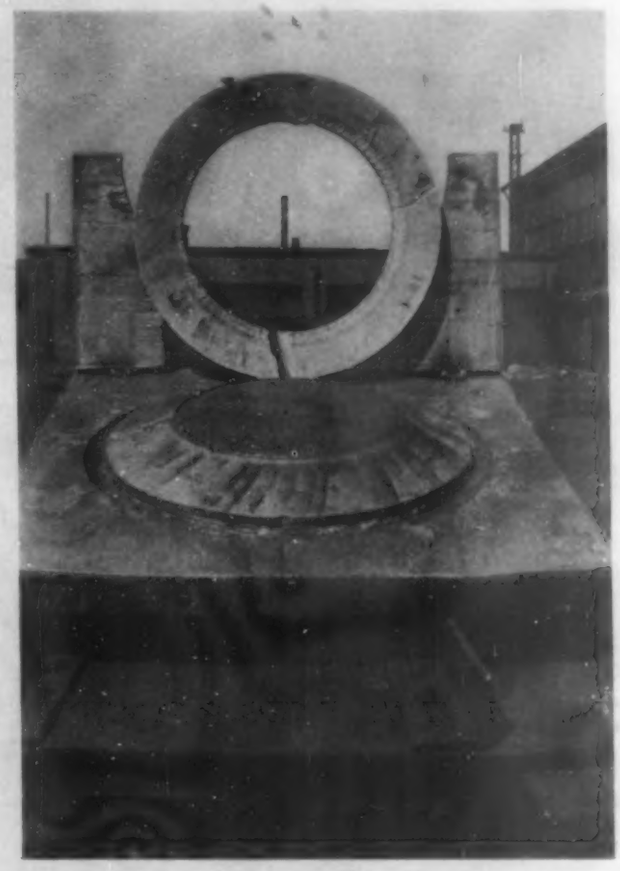


Fig. 4—Gas-Cutting Part from $6^1/_2$-in. Slab

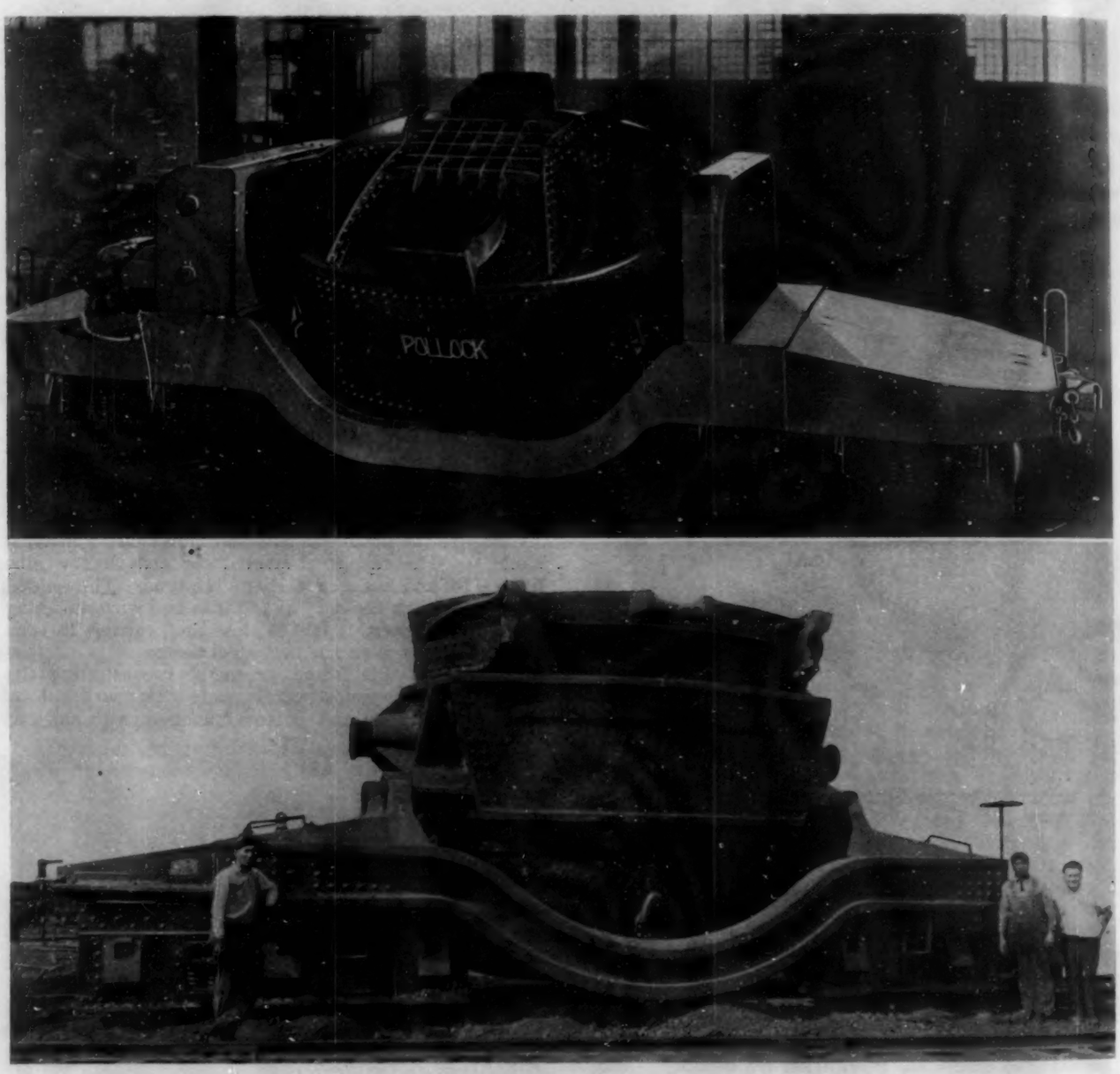


Fig. 5—(Upper) Welded Rolled Steel Metal Car and Ladle
Fig. 6—(Lower) Cast Steel Riveted Car and Ladle

1 1/2-in. plates, forming a box section. Spacer bars, welded to the top and bottom members and projecting through the sides, add to the rigidity of the box section.

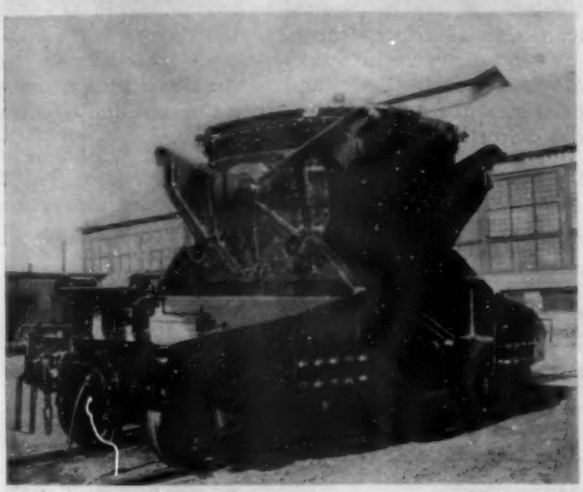
In addition to the weight of the ladle, lining and metal (385,000 lb.), the structure is calculated to take care of a 250,000 lb. impact or coupler thrust, and welding has proved successful in this construction.

Observe the substitution of rolled steel for castings in the 75-ton capacity hot metal cars and ladles (Figs. 7 and 8). Note the rolled steel end frames with interlocking members; that all brake fittings, steps, safety chains, uncoupling lever brackets are welded to the end frame; that the tipping lugs are of rolled steel with the lifting pin welded therein, and that the side frames are of rolled steel, machine-cut by oxyacetylene from a solid slab. The cast steel construction weighs 106,000 lb. The rolled steel construction weighs 94,000 lb.

Figure 9 illustrates the details of construction of the welded car end frame and may be of interest as it shows the method employed to assure the manufacturer of safety in case of weld failures. Observe the use of the mortise and tenon or interlocking features secured by inserting projections of one member into slots cut in other members. It can readily be seen that this construction enables the car frame to withstand the terrific shocks administered by the "gentle locomotive and good-natured engineer on Monday morning." Weld failures, however, have been negligible and, as a result, more reliance is placed in the weld and every new model has more welding embodied in the design.

Columns and base plates for blast furnaces are usually of cast iron, but many furnaces have a grillage and columns of structural steel riveted. Will the next ones be of welded rolled steel? All are designed for equal strength. Compare the finished weights of each (Fig. 10).

The three blast furnace tuyère jackets (Fig. 11) show the abandonment of castings and the substitution of rolled steel. You will note that the second picture shows



Figs. 7 and 8—Substituting Rolled Steel for Castings in 75-Ton Capacity Hot Metal Car and Ladle. Lower car welded

the adoption of rolled steel riveted and that in the third view both castings and rivets have been eliminated and the construction much simplified by the use of welded rolled steel. Observe the ingenuity the engineer has used to obtain support for the welded joint (*A*) by extending the bands (*C*) beyond the joint, thereby making it necessary for the welds which fasten the bands to the jacket to fail before the welded vertical joint (*A*) can break.

In such construction much lighter material is used on account of the support given to the joints by the additional welding of the bands; whereas, with riveted construction both the bands and shell plates are weakened by the rivet holes and the low efficiency of the joint is overcome by adding to the plate thickness to gain the desired result.

Welding is being accepted gradually on other parts of the furnace: gas-seal hoods, receiving hoppers, downcomers, cold and hot blast mains and gas mains, and in all cases savings are obtained and results are generally satisfactory to engineer, manufacturer and user.

Stainless steel tin plate annealing boxes are being tried out to obtain a comparison with boxes made of mild open-hearth rolled steel. Both are of welded construction because the user has ascertained that the welded boxes are much superior to the riveted ones previously used, not only in retaining their shape, but in remaining tight and free from leakage.

In annealing tin plate, a pile of plate is put on a base and covered with an annealing box or cover. The base has an upturned flange or projection and the space between the annealing box and this projection, usually about 6 or 8 in., is filled with sand to make an airtight joint and exclude the atmosphere.

The base, containing tin plate and cover, is then put in a heating furnace and exposed to a temperature of about 1400 degrees for eight hours and, after removal from the furnace, is kept closed for twenty-four hours during the cooling process.

During this time air must be kept from entering the box to prevent oxidization and too rapid cooling.

The boxes, subjected to such severe service by heating to this high temperature, soon get out of shape as the steel at this temperature has lost much of its strength and cannot sustain its own weight.

This distortion in riveted boxes caused leaks in the

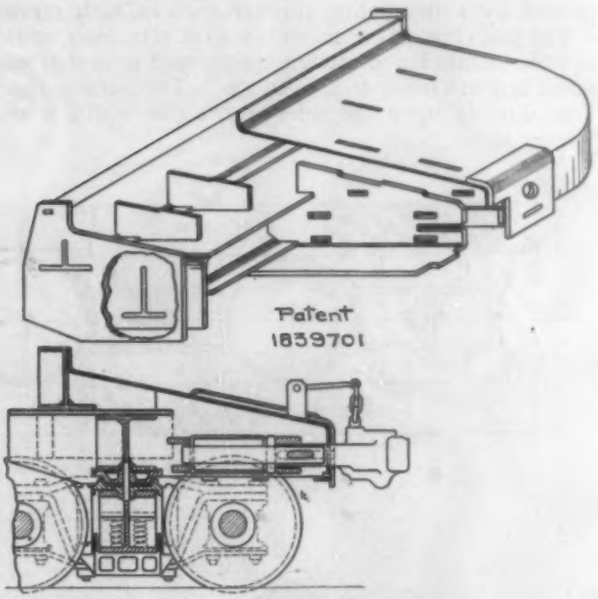


Fig. 9—Welded Car End Frame

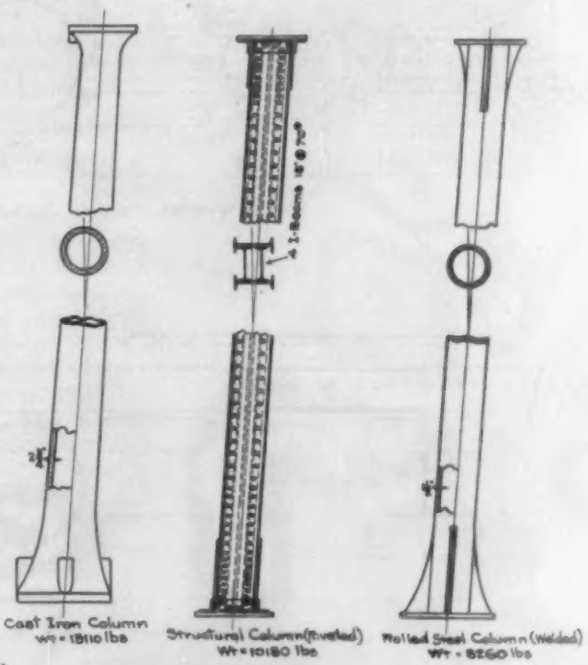


Fig. 10—Columns and Base Plates for Blast Furnace

caulked seams, and the rivets, subjected to this heat, have their elastic limit lowered and consequently the strain on the rivets from the distortion of the box soon loosens them and leaks develop. The welded boxes overcome this fault as the seams keep tight and the boxes withstand from 250 to 300 heats at which time they must be discarded on account of distortion. At this time oxidization has greatly reduced the thickness of the metal.

The stainless steel box is being tried in an effort to overcome the deterioration of the box by oxidization and to save the heating of 2000 lb. of metal which represents the difference in the weights of the two types.

At this writing, the stainless steel box has been subjected to sixty heats and is fulfilling expectations. The reliability of the weld is certainly demonstrated and proved by withstanding the demands of such service.

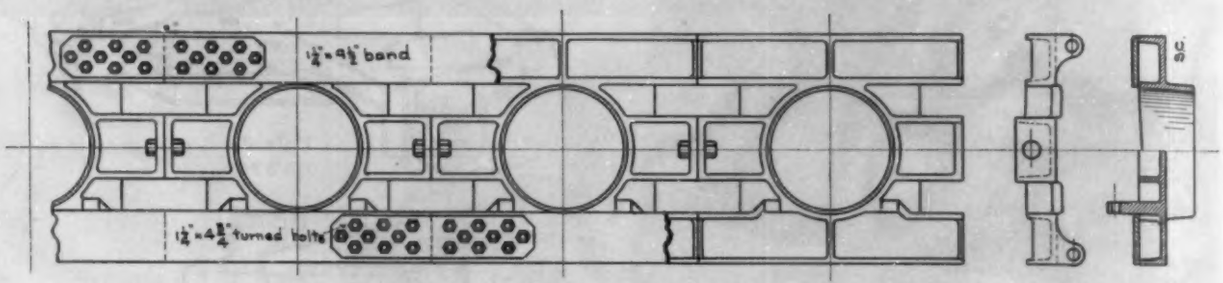
The pan (Fig. 12) 48 in. wide x 15 ft. 0 in. long, is used to hold 40,000 lb. of molten spelter and is heated with seven burners using coke-oven gas. The burners throw heat directly upon the sides of the pan which is supported on the longitudinal center and under the longitudinal angles by brickwork. A temperature of 875° F. is required to keep the spelter in a liquid state during which time wire is passed through it.

The pans are subjected to severe stresses when intermittent operations involve temperature changes from firing and heating. This frequent heating and cooling causes distortion and in riveted pans consequent leaky seams and loose rivets.

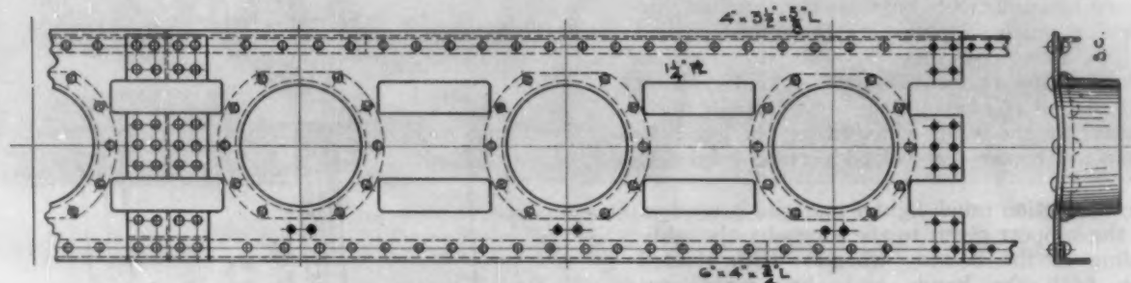
That welded construction has overcome this difficulty is proved by several years of actual service. Both manufacturer and user are asking the steel manufacturer to provide a better material to withstand such usage, as the pans fail not in the welded seams but in the plate.

Figure 13 shows a lead pan made of plates $1^1/_8$ in. thick. The pan is designed to hold 28,000 lb. of molten lead bath at a temperature of 1350° F.

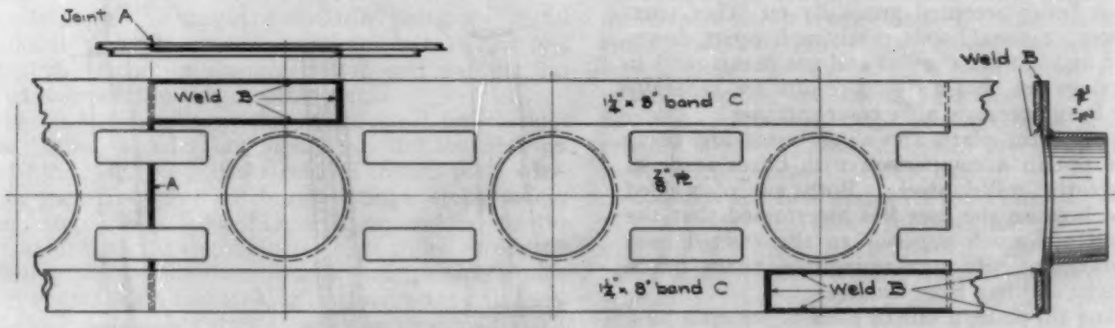
Such pans were previously pressed from a single plate at great cost. This and distortion during service prompted the attempt to reduce the cost and overcome the distortion by this welded design.



Cast Steel Tuyere Jacket. Wt = 22140 lbs.



Riveted Tuyere Jacket Wt = 13060 lbs.



Welded Rolled Steel Tuyere Jacket Wt = 8700 lbs.

Fig. 11

Fig. 12—Welded Spelter Pan 48 In. x 27 In. x 15 Ft. 5/8 In.

Fig. 13—Lead Pan Welded

Needless to state, that welds withstanding such service compel confidence of both manufacturers and users.

Fig. 14—Welded Steel Tin Pot. 2 Compartments

Figure 14 illustrates a fine example of the substitution of welded rolled steel for castings.

Load Test on Welded Roof Truss

By CHAS. H. JENNINGS

✦This paper will be presented at the Fall Meeting of the American Welding Society, in Buffalo, Oct. 6, 1932. Mr. Jennings is connected with the Westinghouse Electric and Manufacturing Company's Research Laboratories.

Introduction

THE use of arc welding for fabricating structural steel has rapidly grown within the last few years because of its flexibility, dependability and economic advantages. The maximum advantages afforded by welding are frequently lost, however, because of the designer's inability to adapt himself to this method of fabrication.

"To reap the maximum economic benefits from the use of welding, it is absolutely necessary for the designer to clear his mind of prejudices to previous details of designs. He must consider a given problem from a fundamental standpoint to be certain that he will develop the most simple structure which will fulfill the requirements. His design must involve as few individual pieces as possible so as to reduce the amount of welding to a minimum. To be more exact, he must strike an economic balance between the cost of structural shapes and plates at 2 to 3 cents a pound against weld metal in place at $1.50 to $3.00 a pound. In other words, the designer must not simply attempt exactly to replace a casting with so many pieces of steel welded together, and duplicating the sections and sizes of the castings. Likewise, the designer must not simply take an existing riveted design for a riveted structure and merely figure on the basis of replacing the rivets with the equivalent in weld metal properly disposed to carry the stresses."[1]

An outstanding example of truly welded design is the roof truss designed by Mr. J. E. Webster[2] for a new building at the Derry, Pa., Works of the Westinghouse Elec. & Mfg. Co. (see Fig. 1). In principle, this truss is of the Warren type but it contains the novel feature of having the tension members constructed from several continuous straps disposed throughout the truss so as to automatically increase the cross-sectional area of the various members in proportion to the loads which they carry. The fact that the tension members vary in cross section in proportion to the loads which they carry makes it possible to stress all of them to the maximum allowable stress, thereby facilitating a lighter, cheaper and more efficient structure. The reduction of weight and cost that is obtainable over welded trusses designed according to present-day practice (already a saving over riveted construction) is as much as 30%.

The roof trusses designed for the Derry building (see Fig. 1) contained a trapezoidal section at the center. This construction was permitted in this case because the roof was of the flat type and there was little or no chance of ever obtaining an unevenly distributed load. The choice of an even number of panels in the top chord would have eliminated this trapezoidal center construction.

This new principle of constructing the tension members of a truss from several continuous straps is not confined to the Warren type truss (the type on which it was first employed). A brief analysis has shown that this construction can be used effectively on such types as the Pratt, Fink and Fan. Typical examples of trusses of this design are shown in Fig. 2.

[1] This quotation was taken from "Modern Applications of Arc Welding" by A. M. Candy, Symposium on Welding, Pittsburgh Regional Meeting, March 18, 1931. (Separate preprint.)

[2] Mr. J. E. Webster is General Works Engineer for the Westinghouse Elec. & Mfg. Co.

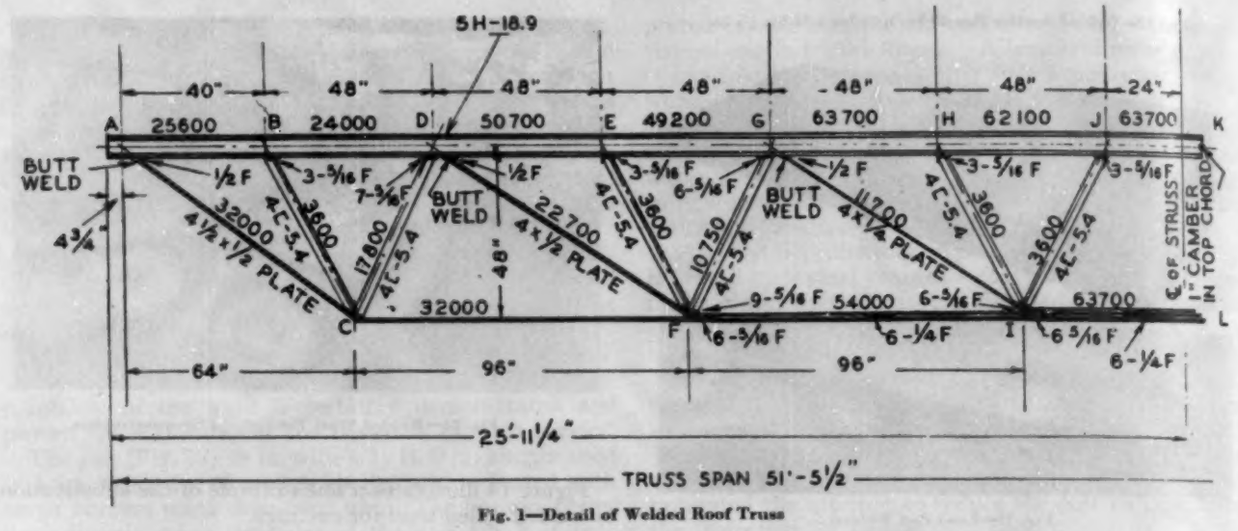


Fig. 1—Detail of Welded Roof Truss

Test Set-Up

The building erected at the Derry Works required ten 52-ft. trusses and thirty 30-ft. trusses, all of which were fabricated at the East Pittsburgh Works of our Company. During the process of constructing the 52-ft. trusses, it was decided to make a load test on a pair of them in order to determine whether or not the actual stresses in the various members checked with the theoretical stresses.

A detail drawing of the trusses tested is shown in Fig. 1. The simplicity of the truss makes it unnecessary to go into detail with regard to its construction. One point that should be noted, however, is the location of the tension straps and the manner in which they unite to form the bottom chord of the truss.

The only important strength welds on the truss are those joining the ends of the tension straps to the top chord. These welds must be sufficiently large to transmit the loads from the straps to the top chord and still not be stressed above the welding code limits (butt welds—13,000 lb. per sq. in. and fillet welds—11,300 lb. per sq. in.).

The test set-up is shown in Fig. 3. The ends of the trusses were mounted on 8-in. I-beams so as to produce a flexible connection similar to that used in the building. The weights used to load the trusses were special rolled steel channels weighing 1100 lb. apiece. These weights were placed in piles at each purlin point, thereby simulating the condition of loading for which the trusses were designed. The first row of weights was tacked welded to the trusses in order to give added stiffness to the set-up.

Test Procedure and Data

The instruments used in making the test consisted of 16 Huggenberger tensometers[3] and 1 Ames dial gage. The tensometers were used to measure the stresses in the various truss members and were located at points as shown in Fig. 3. The dial gage was located under the center of the truss in order to measure the center deflection.

Figure 4 shows a photo of the loaded trusses with all the instruments in place. The fact that the trusses and the load were symmetrical made it necessary to take measurements on only one end of one truss.

[3] The tensometers had a gage length of 2 cm. and measured an equivalent stress of 1250 lb. per sq. in. per scale division.

Pairs of tensometers were used on members *AC*, *CF*, *DF*, *GI* and *JK* in order to correct for any secondary bending that might have been present. Pairs of tensometers were also used on members *FI* and *IL*. The purpose of the two tensometers in these cases, however, was to determine the way in which the load was distributed between the several straps which composed these members (see Fig. 1). Only one tensometer was used on each of the struts *DC* and *FG*. These instruments were placed at the neutral axis of the members, so that only the direct compression stresses would be measured.

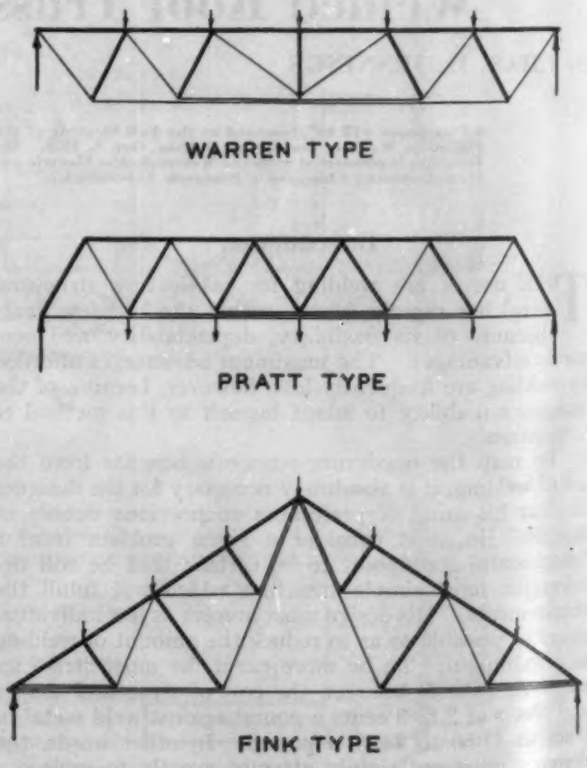


Fig. 2—Typical Examples of Trusses Designed with Continuous Tension Straps

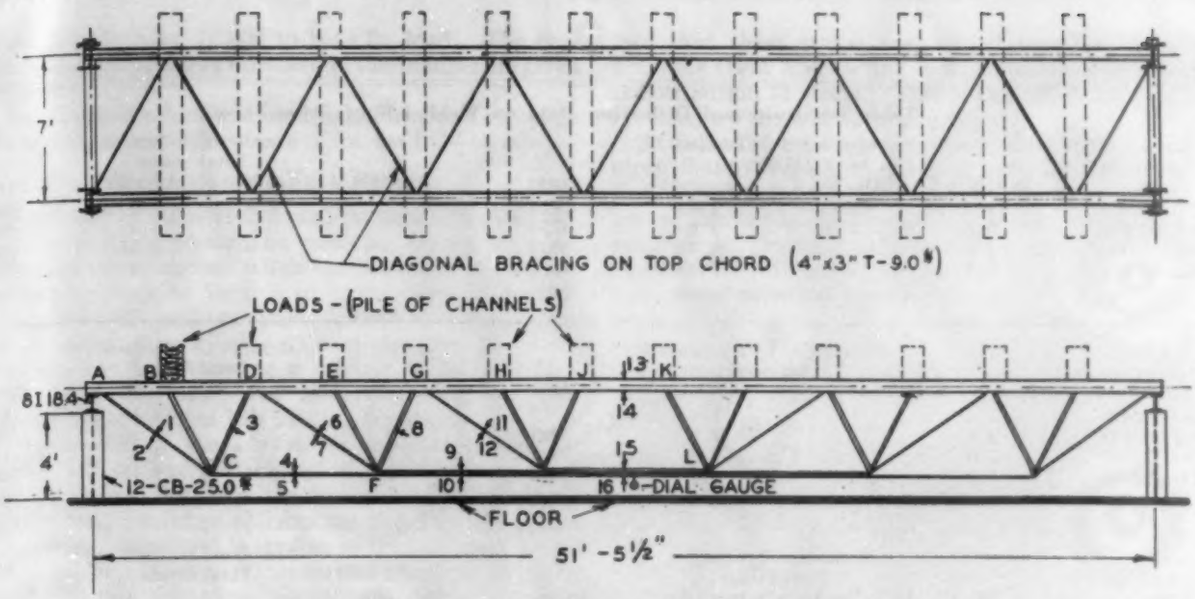


Fig. 3—Roof Truss Test Set-Up

The test was conducted by applying the load in six increments and taking readings of all the instruments after each increment was applied. (A load increment consisted of twelve 1100-lb. channels, one placed at each purlin point, and was equal to 6600-lb. load per truss on approximately $^1/_6$ of the design load.)

The channels were placed upon the trusses one at a time by means of an overhead crane. Successive channels were laid on opposite ends of the truss, starting at the ends and working toward the center, in order to eliminate unsymmetrical loading as much as possible.

The fact that the first row of channels was applied to the trusses before the instruments were placed upon them made it possible to take only five sets of readings. In addition, the instruments contained a certain amount of clearance, and, consequently, the first set of readings did not measure the true stresses. As a result, only four satisfactory sets of readings were taken. These four sets of readings were consistent in every case and definitely showed that the structure acted elastically up to the total load applied (39,600 lb. per truss).

The test data obtained from the load test are tabulated in Table 1.

The stress values for members *AC*, *CF*, *DF*, *GI* and *JK* were determined by using the average readings of the pairs of tensometers used on these members. The difference between readings of pairs of tensometers gave a measure of the secondary bending stresses in the members. It will be noted from Table 1 that this secondary bending was very small in every case. Had the instruments been mounted close to the joints rather than in the center of the members higher bending stresses might have been obtained.

For members *FI* and *IL* the stresses were determined separately for each tensometer (see Table 1). The stresses were computed in this manner because the members were composed of more than one strap (see Fig. 3) and the tensometers measured stresses in different straps.

In order to determine complete load stress curves for loads ranging from zero to full load, the average increment stress measured for the various members was used

Fig. 4—Roof Truss under Full Load Showing Instruments in Place

Table 1—Strain and Deflection Data on Welded Roof Truss

Load Increment on Truss	Member *AC* (Tension) Total Strain Inst. No. 1	Inst. No. 2	Average	Stress	Member *CF* (Tension) Total Strain Inst. No. 4	Inst. No. 5	Average	Stress
13,200–19,800	1.7	2.0	1.85	2310	1.6	2.2	1.9	2380
19,800–26,400	3.6	4.0	3.8	4750	3.7	3.3	3.5	4380
26,400–33,000	5.6	5.0	5.3	6630	5.6	5.3	5.45	6820
33,000–39,600	6.9	8.0	7.45	9320	7.6	7.0	7.3	9130
		Average Increment Stress		2330				2260

Load Increment on Truss	Member *DF* (Tension) Total Strain Inst. No. 6	Inst. No. 7	Average	Stress	Member *GI* (Tension) Total Strain Inst. No. 11	Inst. No. 12	Average	Stress
13,200–19,800	1.3	1.5	1.4	1750	1.5	1.4	1.45	1810
19,800–26,400	2.8	3.1	2.95	3690	3.1	3.2	3.15	3940
26,400–33,000	3.0	5.0	4.0	5000	4.8	5.0	4.9	6130
33,000–39,600	5.0	6.0	5.5	6880	6.3	6.0	6.15	7690
		Average Increment Stress		1720				1920

Load Increment on Truss	Member *JK* (Comp.) Total Strain Inst. No. 13	Inst. No. 14	Average	Stress	Member *CD* (Comp.) Total Strain Inst. No. 3	Stress
13,200–19,800	−1.4	−1.0	−1.2	−1500	−1.6	−2000
19,800–26,400	−3.4	−3.0	−3.2	−4000	−3.3	−4130
26,400–33,000	−5.0	−4.2	−4.6	−5750	−5.1	−6380
33,000–39,600	−6.6	−5.9	−6.25	−7820	−6.9	−8630
		Average Increment Stress		−1955		−2160

Load Increment on Truss	*Member *FI* (Tension) Strain Inst. No. 9	Stress	Strain Inst. No. 10	Stress	**Member *IL* (Tension) Strain Inst. No. 15	Stress	Strain Inst. No. 16	Stress
13,200–19,800	2.0	2,500	1.7	2120	1.0	1250	1.5	1880
19,800–26,400	4.0	5,000	3.4	4250	2.0	2500	2.6	3250
26,400–33,000	6.0	7,500	5.4	6750	3.2	4000	3.9	4870
33,000–39,600	8.0	10,000	6.6	8250	4.4	5500	5.1	6380
	Average Stress	2,500		2065		1375		1595

Load Increment on Truss	Member *FG* (Comp.) Strain Inst. No. 8	Stress	Deflection in Center of Truss in Inches
13,200–19,800	−1.2	−1500	0.180
19,800–26,400	−2.0	−2500	0.181
26,400–33,000	−3.0	−3750	0.177
33,000–39,600	−4.0	−5000	0.181
	Average Increment Stress	−1250	0.180 Ave.

Stress in lb. per sq. in. = strain reading × 1250.

* Tensometer No. 9 measured the stress in the strap continuing from member *DF*. Tensometer No. 10 measured the stress in the strap continuing from member *AC*.

** Tensometer No. 15 measured the stress in the strap continuing from member *GI*. Tensometer No. 16 measured the stress in the strap continuing from member *AC*.

Table 2—Corrected Load Stress Data on Welded Roof Truss

Load on Truss	Stress (Test Results) Member *AC*	Member **CD*	Member *CF*	Member **FG*	Member *DF*	Member *GI*	Member **JK*	Member *FI* Same as *DF*	Same as *AC*	Member *IL* Same as *GI*	Same as *AC*
6,600	2,330	− 2,160	2,260	−1250	1,720	1,920	− 1,955	2,500	2,065	1375	1595
13,200	4,660	− 4,320	4,520	−2500	3,440	3,840	− 3,910	5,000	4,130	2750	3190
19,800	6,970	− 6,320	6,900	−4000	5,190	5,650	− 5,410	7,500	6,250	4000	5070
26,400	9,410	− 8,450	8,900	−5000	7,130	7,780	− 7,910	10,000	8,380	5250	6440
33,000	11,290	−10,700	11,340	−6250	8,440	9,970	− 9,660	12,500	10,880	6750	8060
39,600	13,980	−12,950	13,650	−7500	10,320	11,530	−11,730	15,000	12,380	8250	9570
Design Load					Stress (Theoretical)						
38,400	14,200	−11,400	14,200	−6900	11,350	11,700	−11,600	Av. 12,800		Av. 12,200	

* Negative sign (−) indicates compression. All other stresses are tension stresses.

to extrapolate from 13,200 to zero lb. load. The corresponding stress values obtained in this manner are given in Table 2.

A similar procedure was used to determine a complete load deflection curve from zero to full load.

Discussion of Test Results

The results of the load test are best studied by plotting the data and comparing the resulting curves with the theoretical stress curves. This has been done separately for each member in Figs. 5 to 9, inclusive. The test values were taken from Table 2 and the theoretical values (also given in Table 2) were determined in the usual manner by assuming a loading of 3200 lb. per panel point per truss. The theoretical forces in each member resulting from this loading are shown in Fig. 1.

Examination of the curves for members *AC*, *CD*, *CF*, *FG*, *DF*, *GI* and *JK* (Figs. 5, 6, 7 and 9) show very close agreement between theoretical and test values. This close agreement establishes the fact that the action of the truss under load is similar to that assumed in its design. The flexibility of the various members is partly responsible for the close agreement. Had the truss been of conventional design with more rigid tension members and connections, the test results would undoubtedly have shown larger errors and considerably higher secondary bending stresses.

The results obtained from members *FI* and *IL* warrant special consideration because these members are composed of two and three straps, respectively (see Fig. 1). If all the tension straps were located and proportioned to carry the same stress and were perfectly straight each would carry its full load throughout its entire length. This ideal condition, however, is not always obtainable because of the inability to make all the straps perfectly straight, and the inability to obtain straps from standard stock that are of such size that the stresses in each member will be the same.

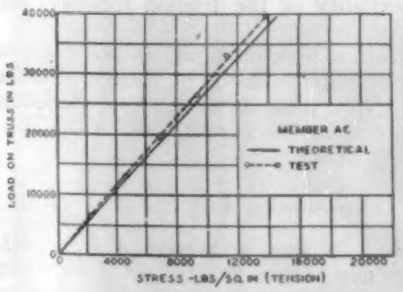
Referring again to member *FI*, it will be noted that the theoretical stresses in the two straps forming this member are of different magnitude (see Table 2). The fact that these straps are welded together, however, prevents them from acting independently, and causes a redistribution of stress. This is the condition that was revealed by the test data (see Fig. 8).

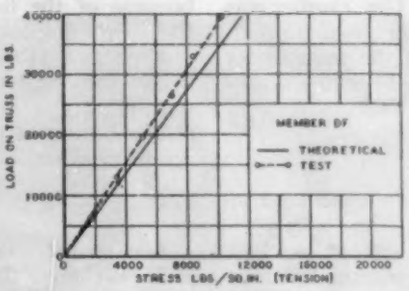
At full load conditions, the test data show that the strap that is the continuation of member *DF* (stress in *DF* is 10,320 lb. per sq. in.) has a stress of 15,000 lb. per sq. in. while the strap that is the continuation of member *AC* (stress in *AC* is 13,980 lb. per sq. in.) has a stress of 12,380 lb. per sq. in. (The average of these measured stresses comes within 10% of the theoretical average for member *FI*, consequently they are nearly correct.) The reason for this redistribution of stress is the result of rigidly welding the straps together at point *F* (see Fig. 1) and the failure to have both straps perfectly straight. A slack portion in one strap could easily cause it to transmit part of its load to the other strap.

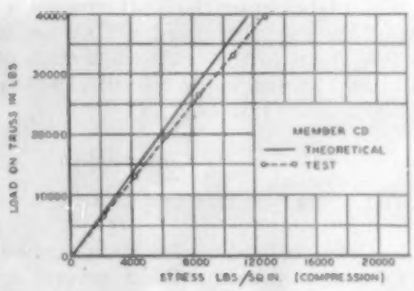
It should be pointed out that in the above discussion, it was assumed that the tensometer readings taken on the two straps forming member *FI* measured stresses resulting from pure tension and not from a combination of tension and bending. It is possible that there was some bending present but on the basis of the small amount of bending obtained in the other members, it was felt that it could be disregarded in this case.

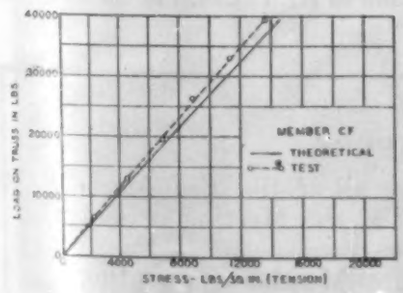
In member *IL*, a condition of stress distribution occurs that is similar to that obtained in member *FI*. In this case, however, it is still more complicated because there are three members instead of two. The measured stresses in the two outer straps of this member were relatively low (see Fig. 8). It is possible that such a condition occurs, however, because by assuming the center strap to have a stress of 15,000 lb. per sq. in. (the stress measured in this strap in member *FI*) it will be noted that the average stress of the three straps approaches the theoretical average (10,940 lb. per sq. in. by test and 12,200 lb. per sq. in. theoretical).

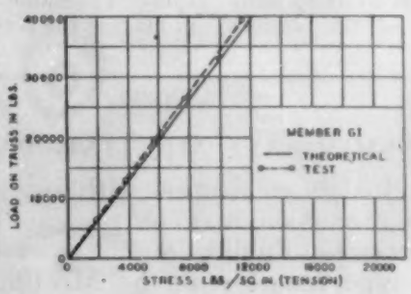
The fact that the several straps in the composite members of the bottom chord did not carry their assumed loads should not be considered an objection to this type











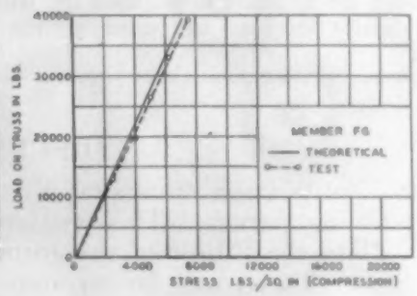
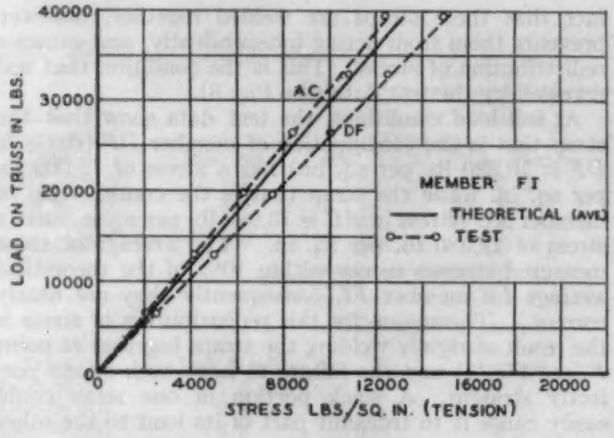
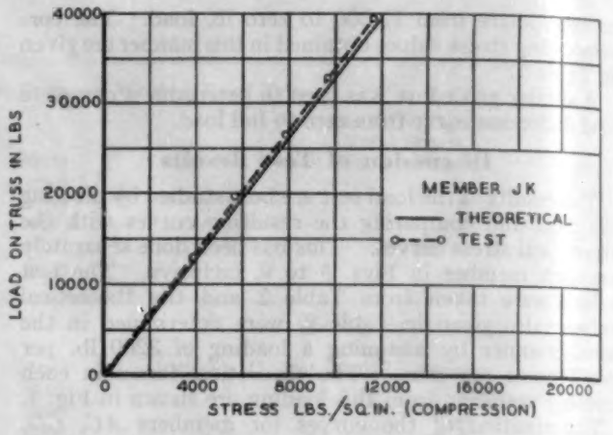


Fig. 5 Fig. 6 Fig. 7

Load Stress Curves





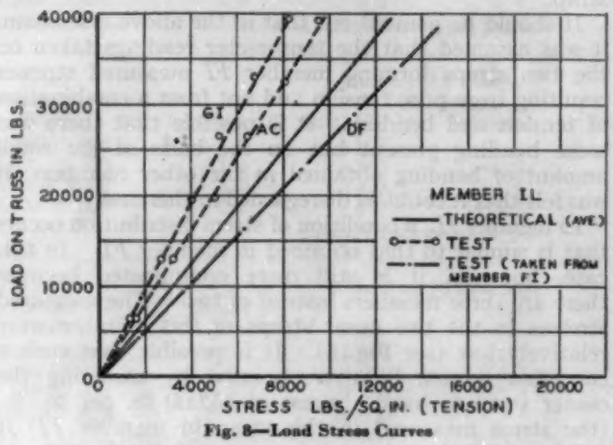


Fig. 8—Load Stress Curves

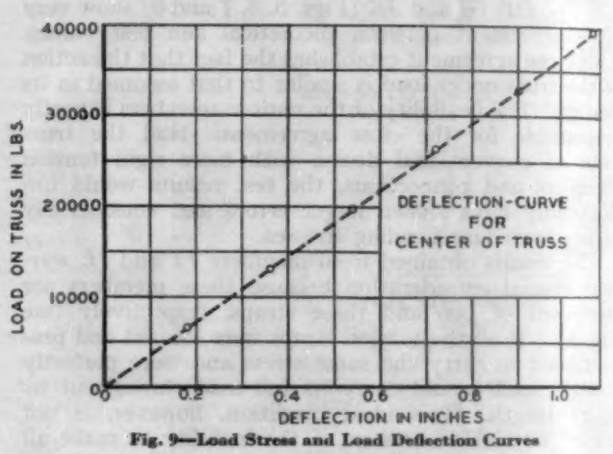


Fig. 9—Load Stress and Load Deflection Curves

of design. Small redistributions of stress such as obtained in this test are not objectionable. Careful proportioning of the tension straps so that they will carry approximately the same theoretical stresses and rigid fabricating specifications to insure that all straps are held straight will insure that this redistribution of stress is small.

When fabricating the 52-ft. trusses, a 1-in. camber was placed in the top chord. This camber was approximately equal to the center deflection of the truss under full load (1.08 in.). As a result, the truss became nearly straight under full load.

Conclusion

The results of this test can be briefly concluded as follows:

1. The method of designing trusses by constructing the tension members from several continuous straps which are disposed throughout the truss so as to automatically increase the cross section of the various members in proportion to the loads which they carry (see Fig. 1) is sound engineering.

2. The actual stresses in the members of such a truss agree very well with the theoretical stresses computed by means of standard methods.

3. The secondary bending stresses in the various members of a truss of this design are relatively low because of the flexibility of the tension members and the joints employed.

4. Strict fabrication specifications are required to insure that all tension straps are kept straight. If the tension straps are not kept straight, an undesirable redistribution of stress may occur in some of the composite members.

Acknowledgments

The writer wishes to give acknowledgment to Mr. J. E. Webster, the designer of the trusses, for making this test possible, and to Mr. F. Cassel for his assistance in making the tests.

DISCUSSION FALL MEETING PAPERS

Written discussion is invited in connection with any or all of the Fall Meeting papers. This written discussion may be presented at the Meeting or sent to the Editor of the JOURNAL for Publication.

There will be no stenotype reporter at the Meeting. Members presenting oral discussion are requested to put same in writing and send to the Editor.

Application of Welding to Pressure Vessels

By P. R. HAWTHORNE

†This is Part "A" of a paper to be read at the Fall Meeting of the American Welding Society in Buffalo, Oct. 6, 1932. Mr. Hawthorne is connected with the Struthers-Wells Company. Part "B" which follows will be presented by Mr. J. C. Holmberg.

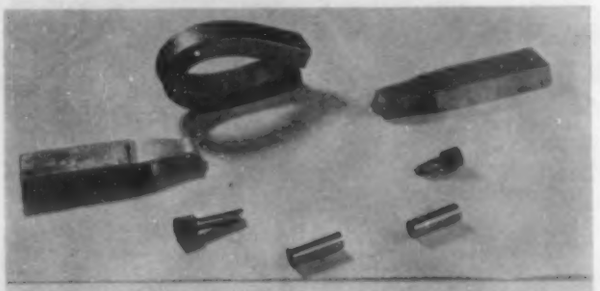
PART A

DEVELOPMENTS in electric arc welding during the past few years have resulted in recognition of the art by users of welded products, as well as the regulatory bodies, as the most efficient method of joining heavy metals to form vessels for high pressures and hazardous service. While formerly its use was limited to repair work and the fabrication of light shells for low pressures, it is now used successfully to join the thinnest of metals, as in automobile bodies, as well as metals of any practical thickness, even six inches or more, for vessels subjected to enormous pressures and for most severe and hazardous services.

For certain classes of vessels, electric arc welding has entirely replaced riveting as well as all other methods of welding, and new applications and uses are continually being developed.

Electric arc welding does not now, as formerly, compete with gas welding to an equal extent. Each method has, in general, found its particular economical and practical uses. For certain purposes the electric arc cannot compete with the gas torch. The improvements made in gas welding and cutting during the last decade are a credit to the manufacturers and engineers responsible therefor. New uses are being continually found and greater economies being effected in the application of the gas torch to cutting and welding. The cutting and shaping of metals by electric arc will probably never be developed to compete with gas, economy and quality of work considered. The gas torch has proved to be a most valuable adjunct to electric welding, particularly in heavy plate, for cutting and otherwise removing metals prior to and during the electric welding operation. It is true, beyond question, that without the gas torch, the preparation of plates over two inches thick would be very expensive and the preparation of

Fig. 1—Complete Set of Test Samples Required for Class 1 Vessels



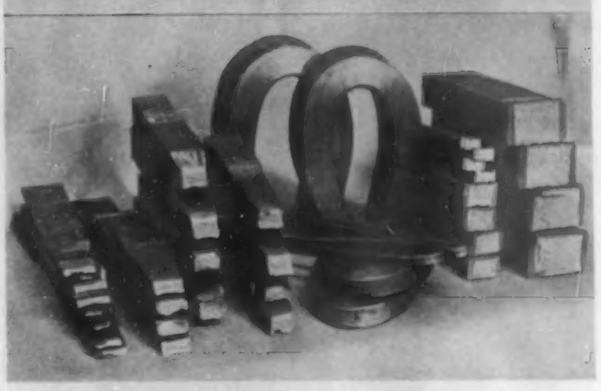


Fig. 2—Complete Set of Test Samples Required for Class 2 Vessels

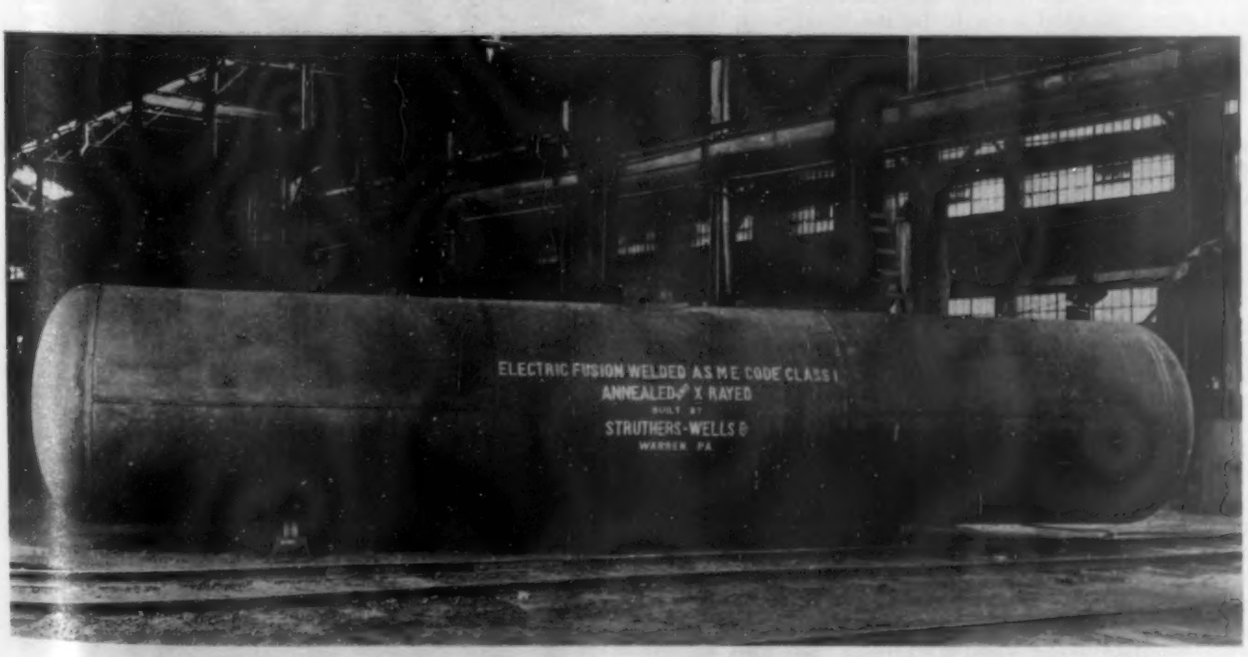


Fig. 3—Welded Vessels for Hazardous Service

Fig. 4—X-Ray Equipment for Testing Vessels

Fig. 5—Furnace for Stress-Relieving Welded Vessels

many irregular pieces of welded vessels would be practically impossible.

The examples of welded products to be herein illustrated have, for the most part, been built in accordance with the A. S. M. E. Code for Classes 1 and 2. Class 1 requires physical tests to be made on sample pieces attached to and welded with shell, X-ray examination of welded seams and stress-relieving by heat treating the completely finished vessel in one unit.

Class 2 requires qualification of welders by making welded test plates of different thicknesses which, when tested, must meet physical standards as set up in the Code.

Figure 1 shows a complete set of physical test samples as required for each Class 1 vessel. In this group is one all weld metal tension specimen, threaded both ends, the tensile strength of which must equal the minimum range of plate used in vessel and the elongation in two inches must be at least twenty per cent. The long straight piece is a flat tension specimen of the original plate thickness, reduced at its sides to make the entire load come on the weld cross-sectional area. The strength of this piece must also equal that of the minimum range of vessel shell plates. The third is termed a free bend specimen, machined four sides, left as near as possible to original plate thickness, and when bent under press or in testing machine the elongation in the deposited weld metal section, on the outer fibers must be at least 30%. The two small cylindrical pieces are specific gravity specimens. Each of these, when weighed, must equal 7.80 times their own volume of water. In the following table are given average results on ten sets of specimens representing ten actual vessels, cut and description of which will be given later.

	Results	Required
All Weld Tension	60,200	55,000
All Weld Elong.	33.3%	20%
Red. Sec. Tension	57,200	55,000
Free Bend Elong.	41%	30%
Specific Gravity	7.88	7.80

NOTE: No single test fell below average. All reduced section tests broke outside of weld.

Figure 2 shows a complete set of samples as required for qualification of each individual welder for Class 2 welding. Welders must requalify every six months. These pieces are cut from plates of thicknesses of $^1/_4$, $^5/_8$ and $1^1/_2$ in. and the results of the tests must meet standards set up in the Code.

Undoubtedly one of the highest compliments yet paid to electric arc welding was in the fabrication of vessels shown in Fig. 3. These are for handling liquids which remain in liquid state solely by being confined under their own vapor pressure. The service is extremely hazardous. Any leakage or failure might result in enormous property damage and loss of life through fire or explosion.

The initial order was recently finished by our Company and the vessels are now in service. They are about seven feet inside diameter, thirty-nine feet long, shell and heads being of plate one inch thick.

The joint efficiency for Class 1 Code vessels, under which these vessels were made, is 90%. The physical tests made on specimens attached to and welded with shell show these joints to be 100% efficient, in that the strength of the welds exceed, by far, the strength of the shell plates. For welding methods used heretofore in the fabrication of vessels for this service, the allowable working stress in the steel has been 8000 lb. per sq. in., as given in the 1931 Edition of A. S. M. E. Code, while the Code allows for these particular electric welded vessels, a working stress of 9900 lb. per sq. in. This figure is based on the allowed joint efficiency of 90%, steel with a minimum tensile strength of 55,000 lb. per sq. in. and a working pressure with factor of safety of five.

This results in an allowable working stress of 23.7% greater than for vessels of this type heretofore permitted.

Fig. 6—Welding Department

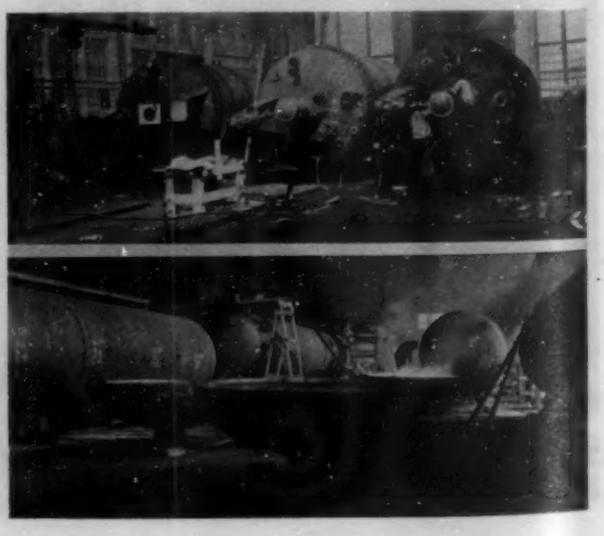


Fig. 7—Three Vessels of Complex Design

The specifications included most rigid tests, in addition to Code requirements.

The hydrostatic test consisted in each vessel being filled with water, pressure raised to 350 lb. per sq. in., each welded seam hammered at six-inch intervals with full swing blows of ten-pound sledge with vessel under 350 lb. pressure, then raising pressure to 475 lb. for period of thirty minutes while vessel was examined for leaks and sweats. Each vessel successfully passed these tests with no one showing any indication of leak. Very accurate work was required in forming the heads and shells and in assembling the tanks. The specifications allowed no offset more than $^1/_{16}$ in. between abutting plates. The rings, of which there were three per vessel, had to be rolled much more truly circular than usually required in order that no point at end of any ring would be offset more than $^1/_{16}$ in. from adjoining ring or head.

The process used was Struthers-Wells Company's "tempered arc," coated electrode; welding being done in a gaseous sheath to prevent contamination of metal while in vapor or highly liquid state, and through a combination of chemical reactions and metallurgical changes produces welds with properties which far exceed Code requirements.

After welding was done, the seams were explored by X-ray. This included every foot of longitudinal and girth seams. These films, placed end to end, constitute a panoramic view of each seam and are a permanent record of the quality of the welds.

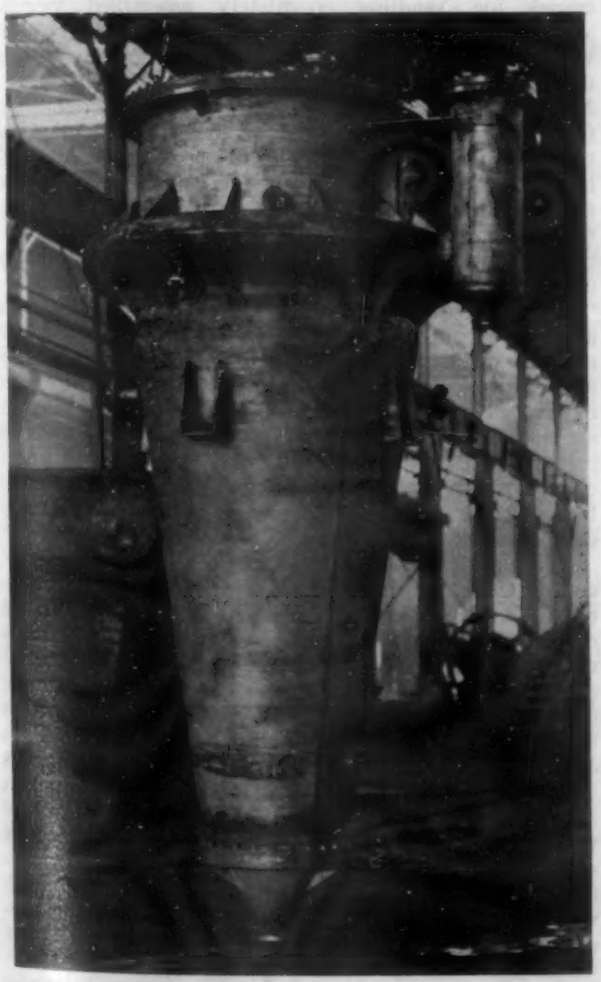


Fig. 8—Jacketed Vessel of Chrome Nickel Steel

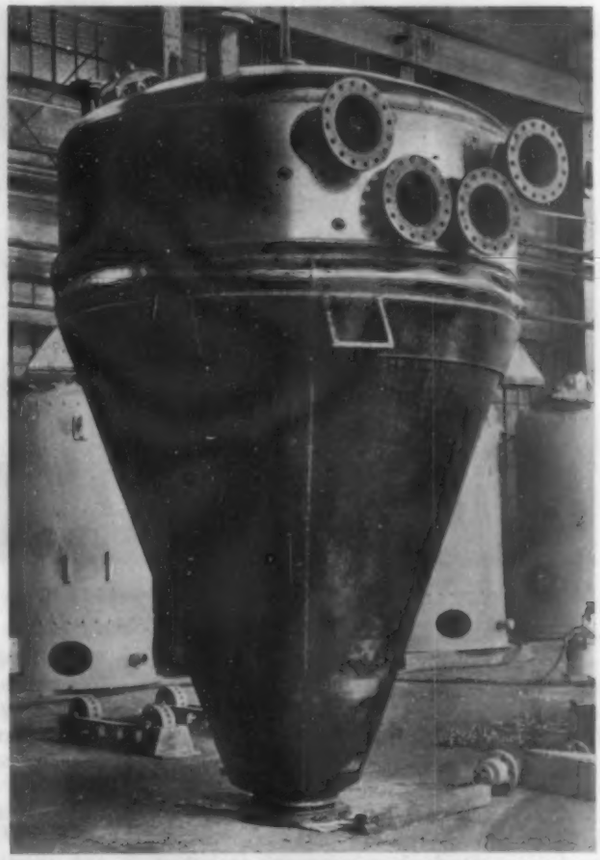


Fig. 9—A Welded Vessel of Complex Design

Complete X-ray equipment of high capacity is required for this work. A general view of this apparatus, with vessel in position, is shown in Fig. 4. This equipment is built especially for the examination of welds in heavy plate and is of much greater capacity than the ordinary commercial X-ray apparatus. The one shown is capable of making satisfactory films of welds in plate $3^1/_4$ in. thick, and on longitudinal seams, two exposures, each 17 in. long, are made at each setting.

After completion, and before the hydrostatic test was applied, each vessel was placed in furnace, the temperature brought up slowly to 1200 degrees Fahrenheit, held at 1200° for $1^1/_4$ hr., then allowed to cool slowly in furnace to about room temperature. Figure 5 shows this furnace, which is of the car type, the dimensions being 13′ 3″ wide x 15′ 3″ high x 82′ 4″ long, all inside dimensions. A bulk head is built into the furnace at about midlength which may be lowered when required for short vessels. The lining and refractories used in the construction are capable of withstanding temperatures as high as 2200 degrees Fahrenheit for heat treatment of alloy vessels and product, of which our Company's output largely consists.

The temperature at forty different points in the furnace is automatically controlled within very close limits. Eight charts record the temperature and time throughout the annealing operation and become a permanent record.

Figure 6 shows one bay of Welding Department with vessels being welded. These vessels are 8 ft. inside diameter, about 45 ft. long and of plate over one inch thick. They are Code, Class 1, and are being built for oil refining service. The oil industry was the pioneer user, through necessity, of electric welded vessels, by

Fig. 10—Welded Vessel 5 Ft. in Diameter with Walls 3 In. Thick

reason of failure of vessels made by other, and now practically obsolete, methods. It is largely due to the success of arc welded vessels in the service of oil refineries that other industries became interested and at the present time practically all major industries use welded products of some nature.

Figure 7 shows three vessels of a very complex design. These are about 10 ft. diameter and about 20 ft. long. Each has a steam jacket over the entire surface except for the top head, jacket being welded up, placed over and welded to tank and made an integral part of the completed structure. Note the large number of openings in the heads and the different angles of the axes of these. There are additional openings in opposite end, both through jacket shell into jacket space, and through both jacket and inner shell. Extreme accuracy is demanded in the alignment of machined flanges and other component parts of vessels of this type.

Inside the vessels are usually provided agitating or stirring devices and scrapers which must run very close to, but not touch, the shell. While these vessels were made of flange steel, many complex designs have been made of alloy steel. Figure 8 shows a jacketed vessel made of chrome nickel steel. A pressure vessel, as indicated by fastenings of openings, is provided with agitators and scrapers driven through gearing mounted on top of vessel.

Figure 9 shows another complex design of vessel. The upper cylindrical portion is provided with many openings set at various angles. The lower conical portion is provided with jacket. Both jacket and vessel proper operate under pressure. In the background are a number of vessels, the design of which indicates they were built for low pressure operation and the stitch riveting along seams indicates Class 3 welding.

Figure 10 shows a vessel 5 ft. inside diameter with walls 3 in. thick. The test pressure applied was 2000 lb. per sq. in. and it is now in operation under varying intermittent pressures up to 900 lb., the rise and fall of pressure occurring almost instantaneously.

The building of Class 1 electric welded vessels requires a vast amount of equipment, considerable of which does not apply to product made by any other method, particularly in case it is intended to equip a plant for the manufacture of vessels of the largest practical sizes in order to be able to serve all industries. To cover the entire field will require, in addition to the usual plate fabrication plant equipment, such items as large plate furnace, heavier rolls, presses and planers, boring mills, additional gas cutting equipment, heavier cranes for handling completely assembled vessels, specially built devices for economical handling of vessels in process of fabrication, larger capacity testing equipment consisting of pumps, gages, fittings, etc., X-ray apparatus with all the accessories, annealing furnace at least 70 ft. long inside, complete physical testing laboratory equipment and considerable chemical laboratory apparatus. In addition will be required the development of a process and the training of the shop organization in the application of same, which is radically different from the application of the ordinary commercial methods.

Further requirements are changes in shop methods and the specific duties of shop personnel, training the men to operate new shop equipment and laboratory apparatus as well as to train these men to think in terms of Classes 1 and 2 welding. This applies equally as seriously to other Departments—Estimating, Engineering and Sales, as well as Executive—all of which must change their long cherished theories and fancies to terms of new type of product made by new and recently developed methods.

For building Class 2 vessels we may omit the X-ray, as the Code, at this particular moment, does not require X-ray. However, it is a valuable accessory to the development of the welding process, and most certainly of value as convincing proof of quality to prospective customers and their inspectors. Exacting purchasers of Class 2 vessels would be more inclined to place orders for Class 2 vessels with fabricators equipped to do Class 1 work than with those who did not have all the means to do the higher grade work. In fact, it is doubtful, as indicated by the attitude of the principal users of welded vessels in regard to the technical features of the processes and product of their sources of supply, if any manufacturer could secure sufficient volume of Class 2 work with which to maintain an organization, without purchasing and installing complete equipment for Class 1 welding.

The annealing furnace may be also theoretically

omitted; however, there are certain designs of Class 2 vessels which require annealing to conform to Code and these are not unusual. Then, as most manufacturers know, it is both economy and good practice, even if not required by Code, to subject Class 2 vessels, or parts thereof, to heat treatment at some stage during or after completion.

The building of Class 2 vessels does not mean, as the term might indicate, that a lower standard of welding will suffice, but there is required a quality of deposit equal to Class 1. Some engineers believe, and some experiences with Customers' Inspectors bear out the contention, that for Class 2 welding, the Code requirements are more rigid than for Class 1. So the use of Class 1 welding is required to do Class 2 work and the cost per foot of welding Class 2 work is by no means less than for Class 1 welding.

While there has been required the development of processes, the design, purchase and installation of new, very expensive equipment, the addition of new methods and radical changes in existing departments, teaching men new trades, and no doubt, in some cases, almost complete reorganization and an enormous amount of time and effort to convince the buying public the merits of the product, all at enormous cost, the result has been almost universal adoption by industry of electric welded vessels for pressures higher and in units greater than heretofore possible to fabricate, more efficient and economical in operation, lighter in weight, at prices not out of line, nor in the end expensive (maintenance considered). This means of fabrication, with all the safeguards required by codes in their manufacture, and the manufacturer's efforts to establish a reputation for quality work, has been a worthy and commendable factor toward actual insurance against property damage and loss of life.

Class 1 and Class 2 electric welded vessels, when made as required by Code and used for service and under conditions intended, cannot be other than 100% efficient and 100% safe.

The Metallurgy of Welds

By J. C. HOLMBERG

†This is Part "B" of a paper to be presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 6, 1932. Mr. Holmberg is connected with the Metallurgical Department, Struthers-Wells Company. Part "A" which precedes this part is presented by Mr. P. R. Hawthorne.

PART B

THE growth of the welding art, whereby it has become possible to produce welds on a production basis that will meet with Insurance and Code requirements, is the history of the development of the bare-wire electrodes into the now almost universally used heavy coated rods.

The start of this development dates to that time when it was noted that apparently like rods did not produce like welds. Investigation soon disclosed the fact that the rods had material differences. This difference was that foreign substances were found upon the surface of the rods; placed there either by intent or accident. Foremost among these was and still is ordinary rust.

From this discovery it was but a short and natural step to the creation of a means of making this foreign matter uniform upon the surface of the rods. It was from this that our present light coated electrodes had their inception.

These electrodes were vastly superior to the old ones, but they still left much to be desired in the way of physical properties and resistance to corrosion.

Careful study of welding and welding technique disclosed that metal in the welds contained a considerable amount of oxides, nitrides and other inclusions.

When this became obvious, it was natural that a remedy be sought. The remedy was effected by literally going to the steel melters and making a comparison of conditions. This comparison showed that in reality when electric arc welding, we have in miniature, an electric furnace, with all its attendant problems. It was natural therefore to borrow from the steel melters certain ideas and apply them to the electric arc welding technique.

Rapid reactions take place during electric welding similar to those in making steel. Large amounts of carbon, manganese, silicon and often sulphur are oxidized out of combination. The products of these reactions are either solids or gases. In addition to these, considerable quantities of oxygen and nitrogen can be absorbed during the exposure of the molten metal to the air.

Many of the solid oxides and silicates formed are trapped in the weld metal, when bare-wire welding. Also many of the gases formed are unable to free themselves during the rapid freezing of the molten metal. The result is that they too become entrapped.

In Fig. 1 is shown a photomacrograph of just such a weld, showing a number of the inclusions noted. Such metal is not of the desired quality and will show relatively poor physical properties. The tensile strength of the section photographed was 48,900 pounds per square inch, and the elongation of the free bend test was but 16 per cent.

When such a weld is subjected to microscopic examination a structure similar to that shown in Fig. 2 is revealed. This photomicrograph, at 100 diameters is from the same piece as Fig. 1.

The now commonly used heavy coated electrodes were developed to improve the quality of welding. They are coated with various compounds which react not dissimilar to the slag of an open-hearth furnace. This coating burns slower than the rod and so forms a shield around the end of the electrode extending down toward the weld. This coating is usually formed of compounds which produce a gaseous atmosphere around the weld so as to eliminate contamination of the molten metal by the air, while in a superheated condition. In addition to these two functions, the coatings supply slag, covering the molten metal during freezing. This delays the cooling and has an annealing action on the weld.

Figure 3 is a photomacrograph of a weld produced with coated electrodes. The weld was cut from a Test Plate attached to a Class 1 of the A. S. M. E. Code vessel. This test plate was cut into the prescribed tests and the results secured were as follows:

REDUCED SECTION TENSILE TEST

Tensile Strength	61,750 lb. per sq. in.
Elastic Limit	47,100 lb. per sq. in.

FREE BEND TEST

Elongation of the Outer Fibers	48.0 per cent

ALL WELD METAL TENSILE TEST

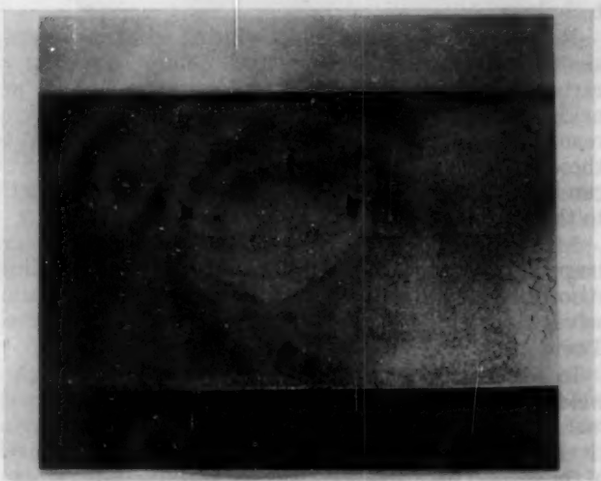
Tensile Strength	62,500 lb. per sq. in.
Elastic Limit	51,000 lb. per sq. in.
Elongation in 2 In	33.5 per cent
Reduction of Area	65.7 per cent

The two density samples showed a specific gravity of 7.876 and 7.865, respectively.

A photomicrograph, shown in Fig. 4, shows the structure in the center of this weld at 400 magnifications. The superiority of this fine grained equiaxed metal over the bare-wire weld shown in Fig. 2 at 100 diameters, is evident.

This improvement in weld metal has been partially obtained by the increased heat used in welding with the heavy coated electrodes. The current used is commonly three times that used with bare-wire electrodes. This results in a greater volume of molten metal, much slower freezing and a resultant opportunity for the contaminations to escape from the weld metal.

Fig. 1—Photomacrograph of Typical Bare-Wire Weld



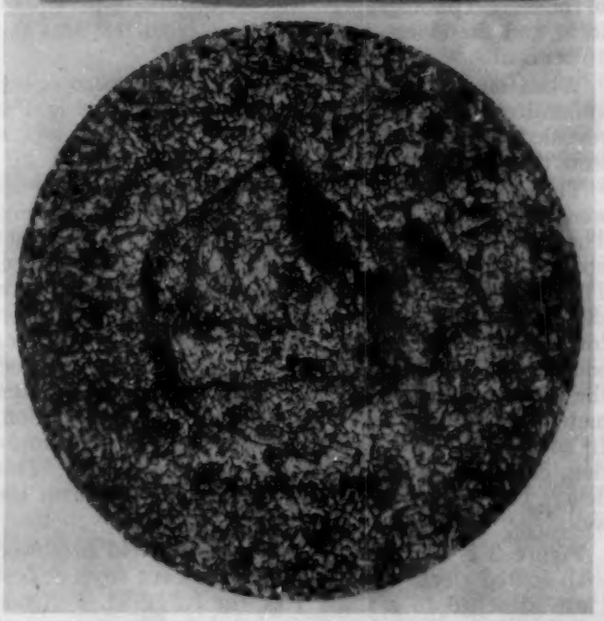
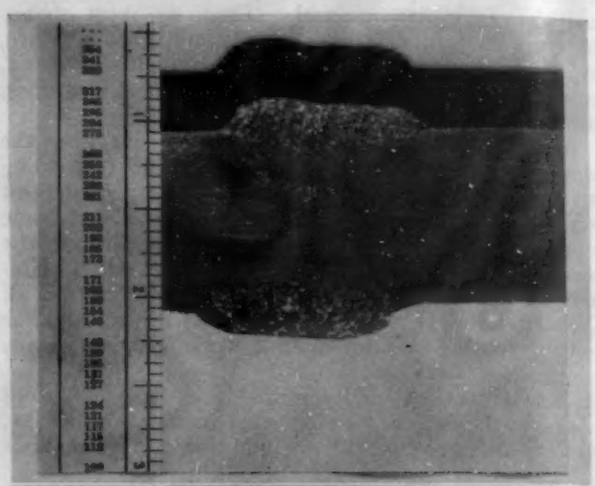


Fig. 2—Photomicrograph of Inclusion Found in Bare-Wire Weld Shown in Fig. 1. 100 Diameters Magnification

Fig. 3—Photomacrograph of a Weld Made with Heavy Coated Electrode



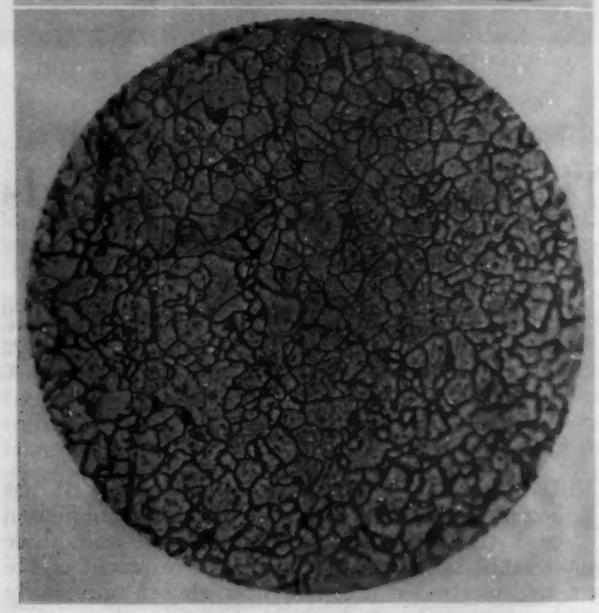


Fig. 4—Microstructure in the Center of the Weld Shown in Fig. 3 at 400 Diameters

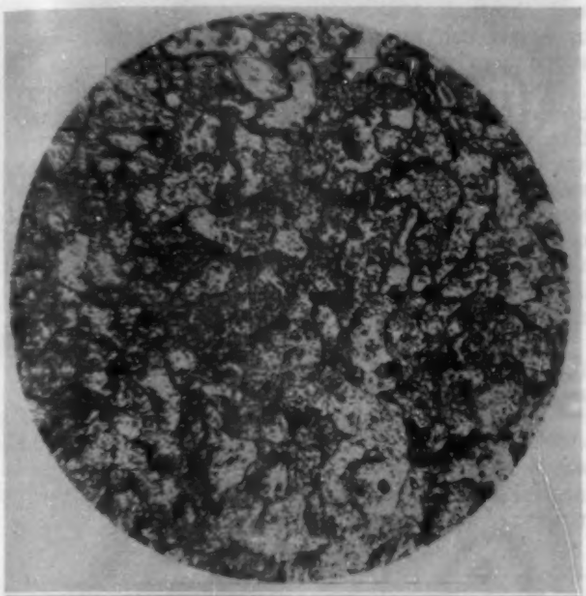
The heat generated during the welding operation has a natural tendency to develop greater stresses than does the bare-wire welding. This is particularily true of seams in the heavier vessels, where the metal is not as free to give as it would be in lighter construction.

It is well recognized that each successive bead will, to a certain degree, anneal it's predecessors. This is shown by Figs. 4, 5 and 6.

Figure 4 shows the center of the weld at 400 diameters; this has been subjected to the heat of practically all the other beads applied.

In Fig. 5 is shown a photomicrograph of next to the last bead and, in Fig. 6, the last or top bead. These show how the metal has undergone tremendous changes, and the effect of the various beads during the welding operation.

Fig. 5—Microstructure Found in Next to the Last Bead of a Weld Made with Heavy Coated Electrodes, at 400 Diameters



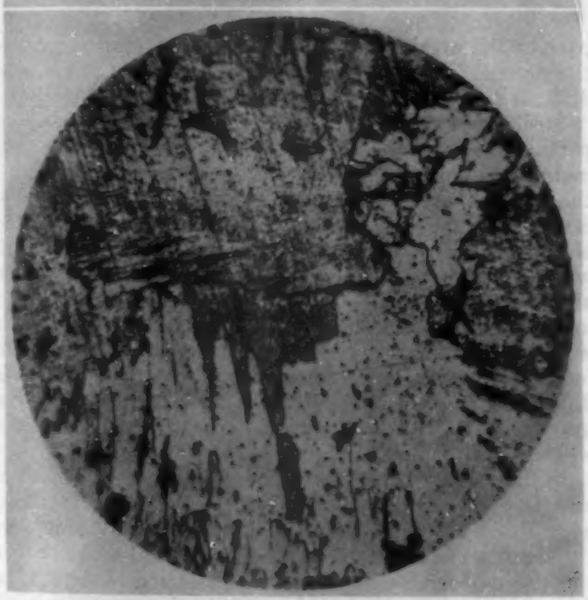


Fig. 6—Microstructure of the Last Bead Applied in a Heavy Coated Electrode Weld at 400 Diameters

However, it is obvious that no amount of successive beads can successfully stress-relieve a vessel. The grain structure is changed but the rapidity of the heating and cooling actions preclude any possibilities of a complete annealing. What actually happens is that each bead to a certain extent anneals the metal underneath it, but upon cooling, stresses are set up through its own contraction, and these stresses extend through the entire weld metal. In addition to this, the welding heat and the contraction of the metal cause strains and stresses to become established in the plate itself.

That these facts are generally recognized is attested to by the actions of the various governing bodies through their establishment of definite instructions as to suitable stress-relieving, through adequate heat treatment, for all vessels under certain classifications. This ruling has made mandatory the installation of suitable furnaces for meeting this requirement.

In the fall of 1928 the need for such equipment was recognized by our company and plans drawn for the construction of a furnace 11 x 11 x 47 ft. This furnace was of the car type, and with porous roof. Oil was the fuel used, being burned in sixteen low pressure burners, eight on either side. Air was supplied by a General Electric blower.

The furnace was operated successfully. However, the need arose for equipment capable of handling vessels of larger dimensions, and the growing use of stainless alloys necessitated equipment that could be used at the higher temperatures required by such materials. As a result, a new furnace was built, capable of annealing the largest vessel that can be shipped by rail, and also designed for temperatures in excess of that needed for the heat treatment of stainless alloys.

Stress-relieving of a welded vessel, not only removes the stresses in the metal, occasioned by the various operations of fabrication, but also has considerable effect upon the different physical properties. When it is considered that to stress-relieve is really to "Draw," as is done to forgings after quenching, a clearer picture of the reactions taking place is obtained. In fact, a vessel prior to stress-relieving might be likened to a forging after quenching in which a vast number of stresses are locked up that must be released before such material will be suitable for use. In forgings it is customary to draw back to increase the ductility to the maximum possible with the tensile strength considered, so that the temperature used must be governed by these factors. In a welded vessel the major point of consideration in the establishment of temperatures for stress-relieving is design and construction. For these reasons it is rarely customary to exceed 1200° F. as above this temperature there is danger of deformation or even collapse.

This relatively low temperature does not have a true annealing action upon a weld. To exert such an influence it would be necessary to go above the critical point of the material, approximately 1550° F. However, that it does have a distinct softening and equalizing effect upon not only the weld metal but also the plate stock adjacent is best shown by the graph in Fig. 7.

This graph is plotted from Rockwell "B" readings taken every quarter inch, on a bar made up of four pieces of Flange steel, welded together to form one continuous piece. After welding the piece was shaped to a $1^1/_4$ in. square x 14 in. long. After shaping the surfaces were ground smooth.

Before the piece was stress-relieved, the readings

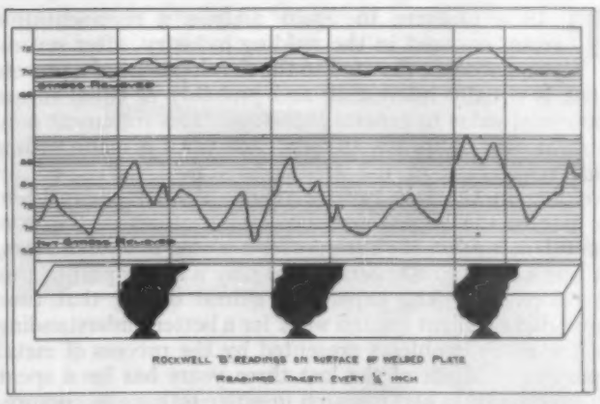


Fig. 7—Graph Plotted from Rockwell "B" Readings Taken Before and After Stress-Relieving. Readings were taken every one-fourth inch for the entire length of the specimen

showed a wide variation as they progressed through the fusion zones, the weld metal and the plate stock. Stress-relieving helped this condition materially. The readings showed less variation and the difference between the plate and the weld metal was negligible. In fact, the most striking feature of the graph is the manner in which the hardness of the material became comparatively uniform and equalized.

Due to the vast number of variables ever present during welding, the reasons for success or failure during the early days of the industry was little understood. Even today, after exhaustive research conducted by leaders in the industry, and others, a comprehensive analysis of the matter is difficult. However, we do know that the Electric Arc Welding Industry is today able to make welds on mild steels fully as strong and dependable as those made by other means and usually stronger than the parts joined. Also welding has progressed from the point where weld metal was virtually all tensile strength and no ductility, to the point where properly made welds contain metal much more ductile than the plate it joins, and still maintains sufficient tensile strength.

Recent years have seen the application of welding to various alloys such as stainless steels, copper alloys and the high tensile strength materials. That these materials can be and are being successfully welded, every day, is common knowledge.

Much of the success of the development and application of the welding industry is due to the metallurgical thought being devoted. Welding is basically a metallurgical problem, and it has been through the definite metallurgical reactions and rules that its progress has been hastened. This fact was clearly seen and appreciated early in the development of the art by leaders in the industry. This is attested to by their establishment of suitable metallurgical departments.

The development of the heavy coated electrode, the manners and means of testing, all bear the imprint of metallurgical thought, for even though the most constructive thoughts and ideas may have originated in some other department, the man fostering these ideas was a metallurgist at heart. For welding is a metallurgical problem and to continue its phenomenal success, it must remain such.

Metal Spraying—the Process and Devices and the Influence upon Welding of Some Recent Developments

By **H. B. RICE**

†This paper is to be presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 6, 1932. Mr. Rice is connected with the Metal Spray Company.

IT IS a pleasure to again address a representative group engaged in the welding industry, after several years absence devoted to the development of a process that is equally interesting and probably of equal future potential value to general industry. This statement may appear over optimistic to some, and yet it is made with a full realization of the tremendous field developed by welding in the last twenty years. As a representative of one of the largest national organizations in the oxy-acetylene equipment business for a period of twelve years, it was a satisfying experience to play a minor part in this development. The experience gained during that time provided excellent ground work for a better understanding of the many problems presented by the process of metal spraying. Much of the last three years has been spent in investigation and research in order to have as comprehensive a knowledge as possible of a process that is little known to the majority of engineers. This is due in part to the attempts of the early promoters to envelope the process in secrecy, to such an extent that it has been difficult to obtain even the basic facts involved.

So little is generally known of the process that it is pertinent to define briefly. It is a method of melting metals and simultaneously atomizing and impacting the molten particles against a surface. If a welding rod is melted with a welding blow pipe and a jet of compressed air played upon the metal as it becomes molten, the result will be a spray of molten metal in the direction of the air blast, and if a properly prepared surface is introduced in the path of this molten metal blast, the molten particles will impact against the surface and instantly solidify to form in a crude way a metal spray coating. If this is difficult to visualize, refer to Figs. 1 and 2 showing a modern type of device in operation. These illustrations will be subsequently described in detail.

If the metal spray from a modern type of device is moved continuously over a sandblasted metal surface, with about the same movement used in paint spraying, the result will be bands or ribbons of metal that are to a surprising degree homogeneous. As many layers as desired may be added and any metal may be applied that can be secured in wire form. Even combustible surfaces such as wood may be coated, as the minute molten particles solidify instantly upon impact and very little heat is transmitted to the object sprayed. All metal surfaces must be sandblasted to chemically clean or remove all oxides, oil, water or foreign particles, and to pit or roughen the surface in order to provide minute "key fasts." The molten particles impact at speeds of from 10,000 feet per minute to 30,000 feet per minute and the resultant bond is very intimate but purely mechanical, probably comparable to the best forms of electro-plating, hot-dipping or, in some cases, to brazing. Metal spraying devices are usually termed guns since the metal is literally shot from the nozzle.

The process is by no means new or novel. It was discovered in Europe about twenty years ago, or shortly after the use of oxygen and acetylene was introduced in welding. Dr. Schoop is generally credited with originating the process but several other gentlemen have contributed generously to its development. The use of the process and devices has been fully controlled by basic

Fig. 1—Gun Fixed and Spraying Metal on Revolving Machine Part

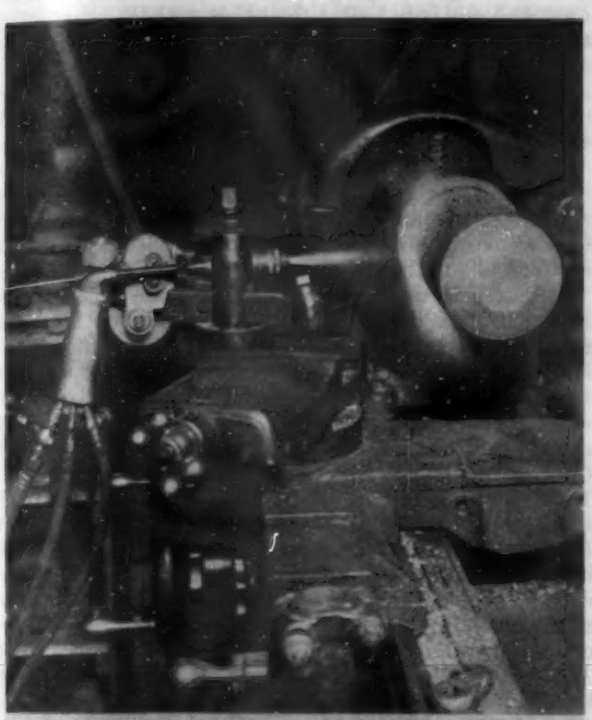


Fig. 2—Spraying with Zinc to Regalvanize

patents most of which have expired recently. It is generally believed that the previous high cost of equipment and operation restricted its general use. The history of welding is not a parallel in this respect as the cost of welding equipment, even in the early days, was low and the field was more or less open to all for development. Metal spraying now is getting into its stride and may well parallel the history and progress of welding in a few years. The process to date has been used to a greater extent in Europe than in America, but in the same manner that America enlarged and perfected welding, it is now removing the objectionable features of this process and shaping it to conform to the requirements of American industry.

Early devices took on a variety of forms that were, of course, crude and secured indifferent results. One early device consisted of a jet of air directed against a gravity flow of molten lead which was contained in a small heated pot. This type was difficult to develop as a hand tool for obvious reasons. Another type used powdered or granulated metal conveyed from a container by means of compressed air through hose lines to a gas flame heating chamber for melting and spraying. High spraying losses and excessive fumes were objectionable features. Metals in wire form came into early use and are the most commonly used to date, but claims are still made for the first two mentioned forms of metal. Heating agencies correspond to those used for welding—oxygen and acetylene or other combustible gases, and electricity by arc and resistance. Electricity as a melting agency has been employed successfully with the same metals used in electric welding. However, the low melting point metals such as lead, tin, zinc and aluminum are used more extensively than in welding and therefore oxygen and combustible gases are by far the most commonly used. In this respect the history of welding may be repeated, but it is believed that in this process electricity will not play so important a part.

Air and other gases under pressure have been employed to atomize and impact the molten metal, and to operate an air turbine to supply power to knurled feeding wheels, between which the wire feeds to the nozzle flame. Other forms of power to feed the wire have been used but air pressure is preferred because of availability and to obtain a hand tool of light weight.

This paper will treat only with the most popular type of gun, using oxygen and acetylene, air blast, air turbine and metals in wire form, two styles of which are shown in Figs. 3 and 4.

Figure 3 is typical of most of the earlier types of devices. The aluminum gear case contains the air turbine and reducing gears, transferring the power to knurled feeding wheels between which the wire is drawn into the nozzle. Wire is used in various sizes, depending upon the melting point of the metals, the average size being 12 gage for lead to 18 gage for steel. In this device one three-way valve on the gun opens and closes the supply of oxygen, acetylene and air, adjustment of pressures being made at the regulators. The wire is introduced into an opening at the rear of the aluminum box-shaped gear case, passes between the knurled wheels inside the gear case, through an opening in the front of the case and into the nozzle. Oxygen and acetylene are mixed at the rear of the nozzle and form from three to six neutral flames surrounding the wire, similar to the preheating flames of a cutting torch. Air is conveyed to a chamber that surrounds the oxyacetylene chamber. The oxyacetylene flames converge slightly to apply the heat upon the wire as it emerges from the nozzle, and the air blast is focused with the adjustable air cap at the end of the nozzle so that it

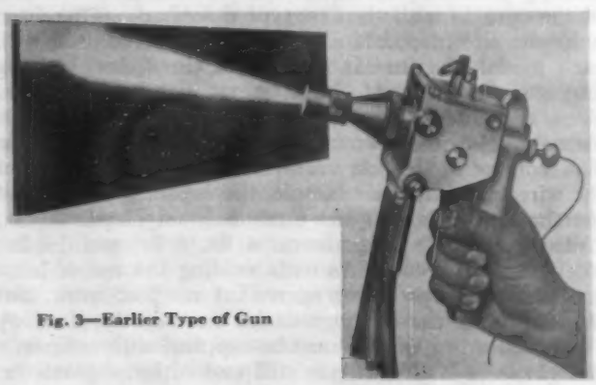


Fig. 3—Earlier Type of Gun

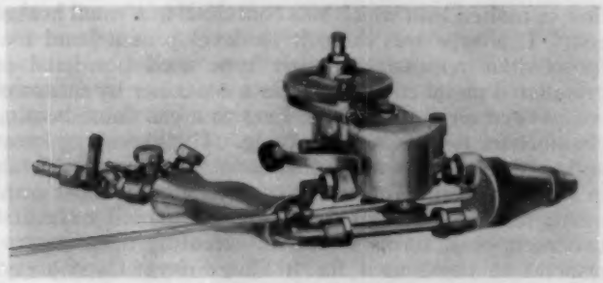


Fig. 4—New Type of Gun

strikes the metal at a point slightly beyond that of the oxyacetylene flames, picking up the metal as it becomes molten, and atomizing and impacting same at high speed against any surface directed. The advocates of this type of gun claim that it is necessary to use small diameter wires, and the consequent small volume of deposit, to obtain tight impervious coatings, or, in other words, sufficiently dense structures to serve useful purposes. Little change in this type of gun has been made over a period of several years. It is efficient when used for thin corrosive coatings or decorative finishes, but cost per pound of metal deposited is high. It will secure tight coatings of soft metals at a thickness of 0.005 in., averages about three pounds in weight and is very convenient as a hand tool. The wire must be introduced into the nozzle before lighting the flame to prevent the possibility of combustible gas backing through the wire orifice into the gear case. The capacity of deposit is limited to approximately one pound per hour of aluminum or steel, about three pounds of bronze, and from five to twenty pounds of soft metals such as zinc, tin and lead.

Acetylene and oxygen pressures used vary directly with the melting point of the metals being sprayed. The commonly used pressures are from 10 to 20 lb. of acetylene and from 15 to 30 lb. of oxygen. Air pressures used are from 50 to 100 lb., and wire speeds from 2 ft. to 25 ft. per minute.

The device in Fig. 4 uses independent valves to control gases, separates nozzle from gear case to prevent the possible collection of combustible gases in the gear case and places the knurled wire feeding wheels outside the gear case to give visible control and prevent wire particles from excessively wearing the worm gears. In this type of gun the wire may be introduced into the nozzle either before or after lighting and the independent control of the gases on the tool permits flame control and adjustment in the same manner as with a welding torch. This type of gun is made in several models or sizes, each model using the same size of wire for various metals. The volume and size of the flame, as well as the speed of the wire, are varied to accommodate the different melting points involved, instead of changing the size of the wire as with the first type described. Therefore, only one size of nozzle and feeding wheels is used with each model of gun. It is made in three models using 12-gage $^1/_8$-in. and $^3/_{16}$-in. diameter metal. The larger size is restricted to the use of metals melting under 1300 Fahr. but the other two models handle all types of metals. The volume of deposit varies directly with the size of the wire sprayed; for example, the capacity per hour of the three models of guns is as follows: lead, 20 lb., 35 lb. and 60 lb; aluminum, 4 lb., 6 lb. and 10 lb.; steel, 2 lb. and 6 lb. As with welding the use of large diameter wires produces somewhat rougher work, but the density of the coatings varies but slightly, if at all. The wire feeding device must be supplied with ordinarily straight wire if the wire is stiff and of large diameter. In such cases wire lengths of from five to ten feet are used and one is fed after the other without interrupting the operation. Soft metals such as lead, tin, zinc and aluminum may be used in coils or continuous lengths in $^1/_8$ in. and $^3/_{16}$ in. diameter. The volume of deposit is increased and the cost of operation is reduced considerably by the use of larger diameter wires.

Applications fall into two general fields: (1) thin impervious coatings over large areas for the purpose of resisting corrosion or for decorative purposes, and (2) heavy coatings over small areas for replacement of worn sections or for the resistance of abrasion and corrosion. The first field uses soft metals principally, the applications are upon the inside of tanks and chambers for the resistance of immersed corrosives, and the outside surfaces of structures for the resistance of atmospheric or vapor corrosion. Zinc, aluminum, lead and tin are used to the greatest extent in the order named. They are applied in thicknesses of from 0.002 in. to about 0.020 in. depending upon the condition to be overcome. It is more difficult to secure impervious coatings with the harder, high melting temperature metals and greater thicknesses are therefore necessary. Often a soft metal is combined with a hard metal to secure a practical and economical coating. For instance, zinc is used as an under-coat or bonding coat for bronze, an average condition calling for 0.002 in. zinc and 0.005 in. bronze when used to resist atmospheric corrosion. Many beautiful decorative effects have also been produced in this manner. This field is well known and has many large possibilities in the replacement of sheet metal linings and the various compositions, such as paint.

The second field uses hard or high melting point metals to a greater extent. It is this field that will probably gain a greater interest from the welding industry since in many respects it parallels work being done or attempted by welding. Such applications involve machine parts such as shafts, sleeves, pump impellers and cases, propellers on ships and many other forms and shapes of machinery subjected to wear, corrosion, abrasion or cavitation. As an example, refer to Fig. 1 showing a spray gun fixed in the tool rest of a lathe and spraying metal upon a circular machine part revolved by the lathe. To the welder it is very apparent that the small amount of heat applied to the object sprayed is distributed uniformly about the circumference in such a manner that no distortion occurs. It is also apparent that a coating may be applied uniformly and of the exact thickness desired. The gun and tool rest are set for a longitudinal movement of from $^1/_{16}$ in. to $^1/_8$ in. per revolution, and the surface to be coated is revolved at from 25 feet to 50 feet per minute. In this field thicknesses of sprayed metal are usually applied at from $^1/_{32}$ in. to $^1/_2$ in. If the surface to be coated is small and the thickness desired large, the spraying operation

Fig. 6—Reclaimed Bronze Pump Sleeves

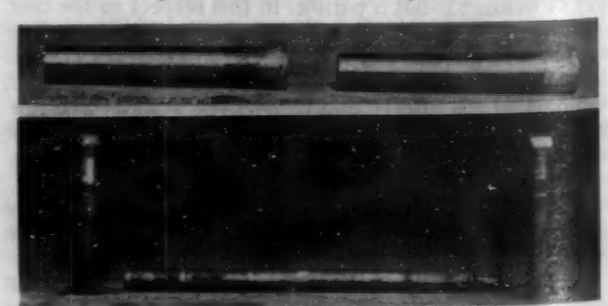


Fig. 5—Bronze Pump Sleeves and Monel Shaft

must be interrupted to avoid over-heating. Usually, however, the area to be coated is such that the operation may be performed continuously. If it is desired to build up a 12-in. bearing on a 2-in. diameter shaft $^1/_{16}$ in. thick, it may be accomplished under ordinary circumstances in one continuous spraying operation.

When coatings up to 0.020 in. thickness are applied a sand-blast bond is usually adequate. On machine parts, however, when using heavier deposits an additional roughening is often employed. For example a shaft may be knurled or a fine thread cut used, in addition to sand-blasting. In this manner the sprayed molten particles are driven into the roughened surface and securely anchored with the parent metal. Flat surfaces which may not be revolved are often roughened with air tools or other hand devices.

An allowance of from 0.010 in. to 0.025 in. is made for machining. Sprayed metal is somewhat similar to cast metal and in some respects may be machined similarly. In machining to size a sprayed bearing either use a small round nosed tool taking fine cuts and finish with emery, or an emery wheel may be employed for the entire operation since but a few cuts are necessary to clean up the surface.

By the use of large diameter wires and a large capacity gun, such as has been recently developed, machine parts may be reclaimed at a surprisingly low cost. For instance, using $^1/_8$-in. diameter rods, which may be applied at the rate of 6 lb. per hour, the total cost including metal, oxygen, acetylene and the labor, will approximate $.50 per lb. for the cheaper steels such as Norway, cold rolled and high-carbon steel, and $1.00 per lb. for the various stainless steels or for monel. One pound of any of these metals sprayed upon one square foot area will obtain a coating about 0.025 in. thick. It is apparent that a few pounds of metal may reclaim an expensive machine part. The restrictions in the use of various metals are less than with welding. Worn areas on bronze pump sleeves for instance may be built up with monel, aluminum on bronze or vice versa; in fact, almost any metal may be applied on any other metal.

It is hoped that this brief description may give a sufficiently clear picture of the process and devices so that it is now pertinent to describe a few recent applications that point definitely toward developments of particular interest to the welding industry.

Figure 1 shows the spraying of one of some fifty carbon steel valve plugs for reciprocating hot oil pumps. Size of plug is 5 in. diameter by 12 in. long; materials used, $^3/_4$ lb. of $^1/_8$-in. stainless steel and 8 cu. ft. each of oxygen and acetylene; spraying time, 10 min. The deposit was 0.010 in. thick and for the purpose of resisting corrosion. No finish machining was necessary as no close fit bearing surface was coated.

Figure 5 shows two badly worn tapered bronze 2-in. diameter pump sleeves and one monel pump shaft $1^7/_8$ in. diameter. The latter has been reclaimed by building up worn area 12 in. long by $^3/_{16}$ in. thick with sprayed monel, then machining to size. Materials used: 4 lb. $^1/_8$-in. monel and 35 cu. ft. each of oxygen and acetylene; time, 2 hr., including machining.

Fig. 6—Pump Plunger

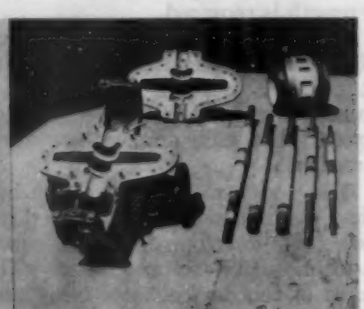


Fig. 7—Reclaiming Supports

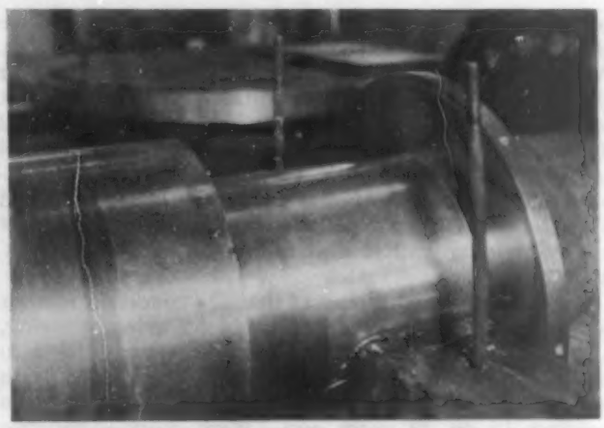


Fig. 9—Sprayed Journal after Final Polishing

Figure 6 shows the previous two bronze pump sleeves reclaimed by spraying monel on the worn areas and machining to size. Materials used on both: $4^1/_2$ lb. of $^1/_8$ in. monel and 42 cu. ft. each of acetylene and oxygen; time, not including machining, 50 min.

In the latter two instances the sprayed monel has given equal operation results to original monel shafts and sleeves, and many of these items have been built up by spraying several times.

Figure 2 shows spraying with zinc to "re-galvanize" welded joints on 12-in. galvanized pipe used at ocean water crossings of a natural gas pipe line. Heavy galvanized pipe resists ocean water successfully and is used extensively but until recently welding of the joints was avoided because it was difficult to protect the area of galvanizing burned off by the welding operation. From 0.010 in. to 0.015 in. zinc is applied requiring per joint about $^1/_2$ lb. of $^1/_8$-in. zinc wire, 2 cu. ft. each of oxygen and acetylene, 2 min. spraying and 2 or 3 min. for sand-blasting.

Figure 7 shows a variety of applications on pump parts. The cast iron case was lined $^1/_{16}$ in. thick on all inside surfaces and the wear ring bearings built to size with stainless steel. Cavitation on the veins of the bronze rotor was filled up and brought to size with sprayed monel. The shafts are from 1 in. to $2^1/_2$ in. diameter and, as shown, were built up as desired with monel, stainless steel and carbon steel. Photo was taken prior to machine finishing. These are typical applications, and are performed at costs of from 5 to 50% of the costs of replacement. The superior type of metal applied obtains longer operating life than the original base metal. Many industries have already adopted such applications as standard practice.

Key-ways, or other adjacent areas, are protected from sand-blasting and spraying by blanking off with rubber or sheet metal. A mechanical roughening was employed on the last-mentioned objects, in addition to sand-blasting, in order to obtain adequate bonds.

Figure 8 is 7-in. diameter by 42-in. long reciprocating pump plunger used to pump oil up to 1500 lb. pressure and is subjected to temperature variations of from 50 Fahr. to 800 Fahr. This is one of the most severe operating conditions in the petroleum industry. A carbon steel plunger lasts about six months, and a stainless steel plunger somewhat longer. Three carbon steel

plungers were first built up with a chrome-manganese steel, the finished sprayed metal averaging 1/16 in. thick. All three failed within four months in such a manner that it was believed that the difference in coefficient of expansion between the carbon steel and the sprayed metal was responsible. Therefore, a stainless steel plunger was sprayed with a similar alloy of equal expansion, but after a similar operation period it failed likewise. In the same plant a similar plunger was built up by welding and it also failed after a few months' operation.

The general conclusion was that the condition was far too severe to correct either by welding or spraying, although it was believed that further experiments with welding might succeed. This type of job is probably to spraying now what steam boiler tube repair was to welding 15 or 20 years ago. With more experience spraying will improve, and undoubtedly overcome such obstacles. The moral of this application seems to be to avoid extreme variations in temperature under such high stresses. Spraying applications involving slightly lower temperature variations, or less stress, have performed satisfactorily.

Figure 9 shows a finished sprayed journal bearing 15 in. diameter by 10 in. long on an armature shaft of a ship. The sprayed metal may be distinguished by the difference in color. The shaft was of the usual carbon steel and became pitted and corroded when carried as a spare part. The owners prohibit welding on such items and furthermore would not turn down and fit with an off-size bearing. The section was machined 1/4 in. undersize, and 29 lb. of 1/8-in. stainless steel applied by spraying, giving a net deposit when machined to size of 1/8 in. on the side. Time of spraying was 4 1/4 hr., approximately 225 cu. ft. each of oxygen and acetylene were consumed.

Although the spraying was almost continuous the highest recorded thermometer temperature of the shaft was 180 Fahr., scleroscope hardness of shaft was 20, rod used for spraying 32 and sprayed deposit 37. A prior laboratory test on a smaller sprayed bearing, compared with a similar steel shaft bearing, both run in various types of bearing metal and, with various loads, showed almost identical results in oil consumption and running temperatures. A chemical analysis of the rod and sprayed deposit showed 50% loss of the carbon, 15% loss of the chrome and no loss of nickel.

Space and time will not permit giving more details on this or other applications. This article is based upon research work, investigation and performance of over 200 field applications, each of which, to be successful, has had to earn its way and demonstrate its worth in modern industry, along with the many other tried and proved methods of reclamation or production.

These have included the building up of almost all types of shafting, sleeves and liners, from one inch to 15 in. diameter, for the purpose of resisting corrosion and abrasion, or both, reclaiming and protecting the interior surfaces of pump cases and valve bodies with sprayed lead, stainless steel, monel and other metals, the use of chrome steel in petroleum refineries as applied to fittings and connections handling hot oil, and the lining of bubble towers and reaction chambers with sprayed metal to resist corrosion, building up cavitation on pump impellers and ship propellers, protecting condenser heads by lining with sprayed lead and by protecting aluminum crank cases from the action of ocean water by using sprayed lead. The worn inside areas of several compressor cylinders have been built up with sprayed metal and machined to size which apparently opens up a very large field. Several blowers handling acid vapor have been successfully coated with sprayed corrosive resisting metals and the results obtained have justified customers in proceeding further along this line. A 9-in. diameter cross-head pin for a stationary steam engine was built up with sprayed metal and was inspected after two months' service and found to be in very good condition. This gives encouragement to the use of sprayed metal under some of the most severe bearing requirements. The interiors of several tanks or acid containers have been protected by sprayed lead. The condition after several months of operation was quite satisfactory. In the aluminum and zinc fields over large areas, quite a number of meter housings have been sprayed with thin coatings to replace paint and one large public utility company, after extensive tests, contemplates protecting the exterior surface of several large gas holders, each involving over 10,000 sq. ft. area.

It would be a pleasure to give further examples and more details as many interesting stories could be presented, but it is hoped that sufficient information has been given to demonstrate that the process has large potential value and is probably now where welding was 15 years ago. Although many mistakes were made in welding in the early days, many more have been made in spraying. The progress of the process has been further impeded by insufficient knowledge of its limitations, and sometimes by deliberate exaggerations of its merits. It has a sufficiently large field in its present form and scope to claim the interest of industry, and it has sufficient potential values to whet the mental appetites of the most experienced engineers. Experience has clearly pointed out, however, that there are many limitations and that the ambitious engineer will travel the fastest who knows these well. They may readily be learned by any intelligent mechanic, and may then be avoided or counteracted, or experimentation may overcome and add other chapters to the development of the process.

Gun operation may be learned in a few hours. It compares in operation skill with a cutting torch. Average applications may be made immediately but some experience must be acquired before attempting some of the more difficult deposits.

There is no question but that a welded fusion bond is superior, yet even a welder sometimes brazes to avoid over-heating. Spraying is a further step in the same direction since it obtains an ideal condition with relation to heat transfer. This advantage is often of so much value that regardless of the unequal quality of the bond, spraying can perform a better job. No preheating is necessary and no heat strains need occur in spraying. Welding has the advantage in heavy deposits over small areas, as spraying is more economical with thin deposits over large areas. The tensile strength of welded metal is much higher; sprayed metal is of small value for joining metals or wherever high tensile strength is required.

Machine parts spraying has been covered more fully than other applications at this time, not only because it parallels welding applications, but because recent improvements have lowered the cost of spraying to the extent that such applications are now economical and practical.

The spray process does not have the disadvantage that welding had in the early days with respect to the necessary development of adequate supplies, such as oxygen, acetylene and rods. The objectionable features of the device have been and are being perfected so that they may be applied as conveniently as welding.

Metal Deposition in Electric Arc Welding

By GILBERT E. DOAN *and* J. MURRAY WEED

†This paper is to be presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 4, 1932. Prof. Doan is Associate Prof. of Metallurgy, Lehigh University. Mr. Weed is connected with the Welding Engineering Department, General Electric Company. Report rendered to the Fundamental Research Committee of the American Bureau of Welding.

IF A steel wire and an object to be welded are connected to the terminals of a generator and touched lightly together, an arc will appear between the tip of the wire and the surface of the object. The tip will melt rapidly and will deposit metal into the crater which has formed in the object below it, or above it as in overhead welding. Whether the deposited metal passes through the arc as vapor, or as mist, or as globules larger than mist, has long been under discussion as has also been the nature of the driving force of transfer, particularly in overhead welding. Metal transfer is one of the most important functions of the welding arc.

Some students of this phenomenon have thought that the larger part of the metal is transferred as vapor[1] which

[1] A. W. Slocum, *The Welding Engineer*, January 1921.

Fig. 1—Thread Shaped Transfer

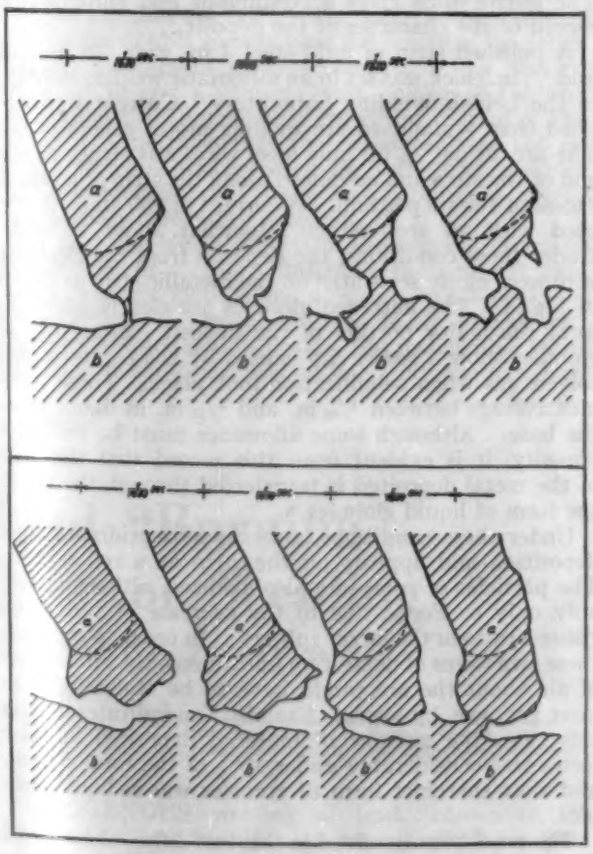


Fig. 2—Mushroom Shaped Globules

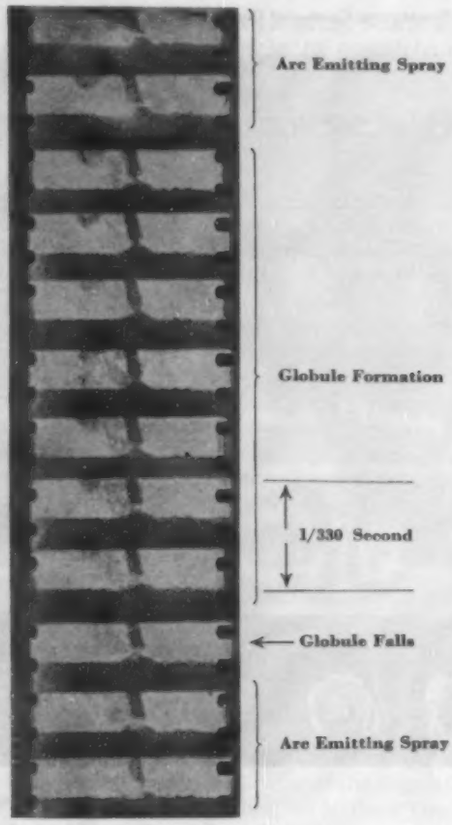


Fig. 3—Thun's High Speed Photography

is generated at the tip of the wire (electrode) and condensed in the crater of the work (object welded). Such action, they believe, would be facilitated if the work crater were cooler than the electrode tip, as they point out in connection with the much larger thermal capacity of the work. Others,[2] pointing out the large amount of energy required to vaporize the metal at the tip of the wire, have reached the conclusion that the larger part of the metal must be transferred as mist or globules of molten metal. These have differed as to the exact mode of liquid transfer. Some[3] have attributed the driving force to the evolution of gas within the melting tip, resulting in a succession of tiny explosions which discharge particles of the metal. Others[4] have explained the transfer as resulting from the forces of adhesion and surface tension between the molten metal on the tip and that in the crater when the two liquids touch each other.

Another theory recently revived[5] accounts for the force necessary to separate the globules from the electrode by citing the "pinch effect." Finally, this last theory has been supplemented[6] by pointing out the tremendous current density existing in the neck or filament of metal formed just as the globule is being separated from the electrode. This tremendous current density results in vaporizing the filament, thereby producing a high pressure of vaporized iron to propel the globule. Although the figures for temperature and pressure suggested in the latter case seem high, (13000° C., 1000 atmospheres of vapor pressure, a force of 10^6 dynes), the

[2] Escholtz, *Trans. A. E. S. XXXIX*, 1921; Doan, *Trans. A. I. E. E.*, 1930.
[3] R. G. Hudson, JOURNAL OF THE AMERICAN WELDING SOCIETY, 1, No. 1.
[4] Escholtz, *Trans. A. E. S. XXXIX*, 1921.
[5] Creedy, *Trans. A. I. E. E.*, 1932.
[6] Ludwig, Discussion of Creedy's paper above.

reprint in Engineering Lib-Lehigh Circular #85 Jan #70 Jan 1933.

Fig. 4—Separating Causes of Deposit of Arc Welds

Fig. 6—Deposit (Photo) and Corresponding Oscillogram

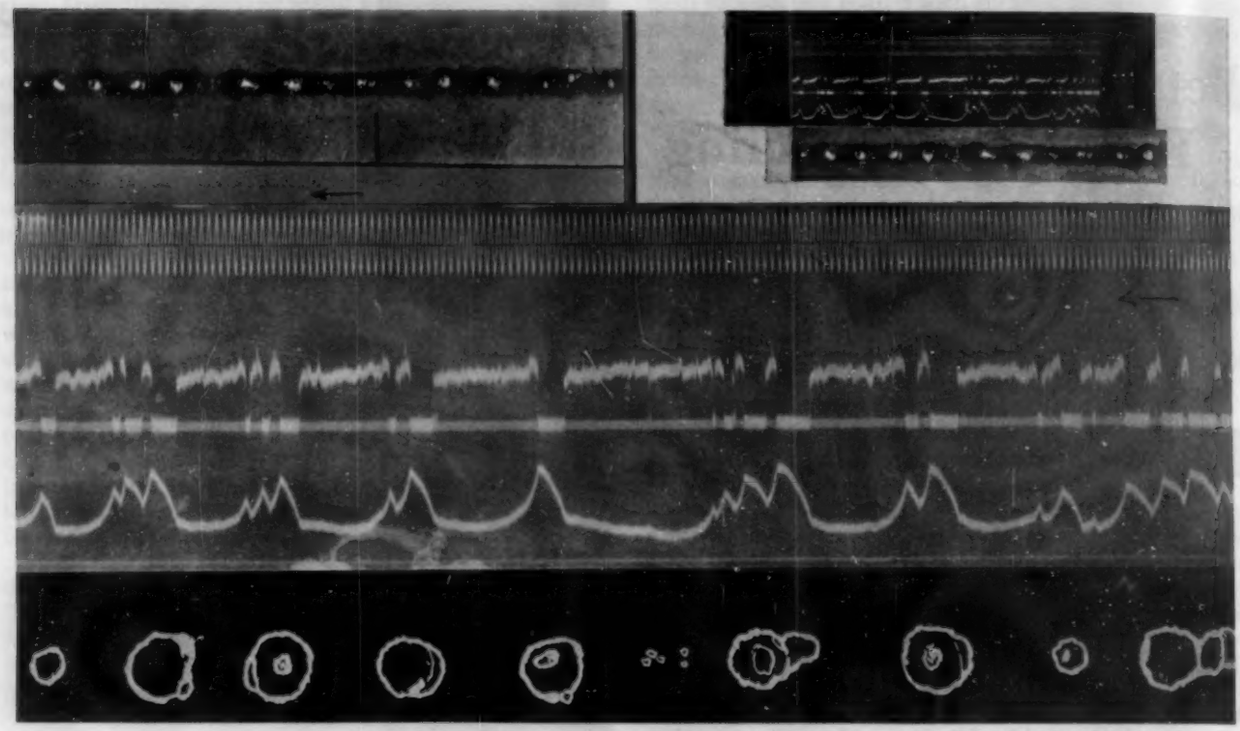


Fig. 5—Deposit (Sketch) and Corresponding Oscillogram

present writers are disposed to accept all of these various theories as involved in the dynamics of overhead welding. For ordinary flat welding we have in addition to these the force of gravitation.

In some experiments at Schenectady, Hoyt and Brophy found that while they were able to do overhead welding with ordinary steel wire they were unable to do overhead welding with a wire of very pure iron, free from gas. This would seem to indicate that the combined action of pinch effect and surface tension, or pinch effect and vaporization of the pinched part of the conductor, is not sufficient to transfer the metal against the force of gravitation without the help of the expulsive action of gas contained within the melting tip of the electrode.

All of these theories and experiments emphasize the importance of the mechanism of transfer of metal, and the incomplete state of our knowledge of its nature.

A partly successful attempt to record by high speed continuous photography the forms in which metal is transferred through the arc has shown that some metal is transferred as globules and some as threads. The instantaneous conditions revealed are shown in the sketches[7] of Figs. 1 and 2 and in the photographs[8] of Fig. 3. The time intervals are marked on these figures in fractions of a second. This method, of course, would not show the metal which might be transferred as mist or as vapor.

The present paper discloses a new and direct method of investigating this subject, and one which records ALL of the possible forms in which metal is transferred through the arc. A polished metal strip or metallic mirror is moved under the welding arc so rapidly that all of the forms of metal deposition are distinctly separated from one another on the surface of the strip. Each form retains its identity and is easily recognized, whereas, in ordinary welding, the globules, mist and vapor all merge in the molten crater and lose their identity at once. The mirror thus gives a continuous and chronological record of the character of the deposit.

A polished strip of mild steel 4 in. wide, 36 in. long and $^1/_4$ in. thick was set in an automatic welding machine in the Lehigh Welding Laboratory. Current was supplied from a standard arc welding motor generator set. The arc, using $^5/_{32}$-in. mild steel wire, was struck at one end of the strip and advanced along the strip at a rate in excess of 100 in. per min. A current of 150 amperes was used with an arc voltage somewhat above 20 volts. Under these conditions, the deposits from the electrode wire were nicely separated on the metallic strip as shown in Fig. 4. The flattened globules are clearly shown to form the major portion of the deposit. Many of the globules show a gas cavity caused by the escape of dissolved gas when solidification took place. These globules average between $^1/_{16}$ in. and $^3/_{16}$ in. in diameter at the base. Although some allowance must be made for porosity, it is evident from this record that the bulk of the metal deposited is transferred through the arc in the form of liquid globules.

Under these conditions, any vapor is oxidized before deposition and appears on the strip as a red powder. The particles of spray are also oxidized, although probably only to Fe_3O_4, due to the decrease of surface-to-volume ratio in the larger spheres. In order to condense these two forms of deposition unoxidized, the atmosphere of air about the arc would have to be replaced by an inert gas, say, by argon. Examination indicates that, in this case, the amount of material deposited in these forms was considerably under 10% of the total deposit, and that the chief form of transfer was as liquid globules.

The conditions involved in this test differ, of course, in some respects from those of ordinary welding. For in-

[7] A. Hilpert, *Technisches Zentralblatt*, Berlin, 1, No. 4, Aug. 1929.
[8] A. J. Neumann, *Technisches Zentralblatt*, Berlin, 1, No. 3, Feb. 1929.

stance, the heating of the strip under the rapidly advancing arc is insufficient to cause crater formation. Surface fusion does take place, however, beneath each globule, even at this speed, as examination shows the globules are tightly welded to the plate and resist removal by the chisel. The temperature of the strip under the arc has, therefore, been at least 1500° C. (the melting point of steel). A temperature considerably higher than this (probably 2450° C., the boiling point of iron) exists at the crater in normal welding and more heat is, therefore, radiated from the crater to the wire tip. But the amount of heat so radiated to the globule on the tip of the electrode, as calculated by the Stefan Boltzman law, seems to be less than 10%. This would not be sufficient to vaporize any considerable proportion of the globule before it left the wire and thus would not change appreciably the proportion deposited as globules. The conditions of this test thus are at least enough like those of ordinary practice to render them suitable for comparative investigation of the basic phenomena of deposition.

Oscillographic records of the instantaneous values of current and voltage of the arc accompanying each series of depositions were taken on a 6-foot film. A section of one film, corresponding to the deposits to the left of the vertical line on Fig. 4, is reproduced in Fig. 5 which also shows the 60-cycle timing wave. The deposit accompanying each current peak on the film is sketched below its own peak, in the same figure. Figure 6 shows the actual deposits below the oscillogram. The accuracy with which the oscillogram records the operation of the depositing mechanism is striking. A number of interesting discoveries are revealed. First, that the size of the current disturbance on the film corresponds quite well with the size of the globule deposited on the strip. For instance, the overlapping globules sketched at the extreme right of Fig. 5 correspond to the group of current peaks on the film above it. The same correspondence holds for the double globule near the center of the series. The tiny globules of spray seemed to bridge the arc sufficiently to give a voltage "zero," although the time was too short for appreciable growth of current. This voltage zero indicates that the deposition was not entirely a spraying process even for these tiny globules. The same momentary voltage zeros appear in several other places where spray is found.

The next globule to the left of the sprayed group (in the direction of motion) illustrates the simplest case, namely, a single globule and a single current peak and voltage valley. Likewise, the next to the left shows a double globule and double peak. But its neighbor (third from left) and also the second one from the left, both show more peaks than globules, which appearance may, of course, be due merely to complete merging of the globules before solidification.

It may be interesting to note that the largest peak of a group is nearly always the first one, possibly indicating the transfer of accumulated liquid at the tip of the electrode. Also, one notes that between the peaks of a group the voltage rises to full arc voltage, with a very short overshoot of voltage above normal, whereas the current in the valleys between peaks does not drop fast enough to reach the normal current value in the short interval. The ordinary ammeter and voltmeter used in welding show, of course, only the average current and voltage, and do not show these rapid fluctuations.

In general, the correspondence between metal deposition and oscillographic record is surprisingly accurate. Twelve complete strings of globules with oscillograms to accompany them were made, using a variety of electrodes, currents and speeds, each with the same general results as are described above. Only one of the twelve records is reproduced here.

Conclusions

These experiments indicate that liquid globules are the chief form of metal transfer, although there is some metal transfer as vapor and mist. A close correspondence is seen between the individual types of deposit and the individual features of the current and voltage waves on the corresponding oscillogram. The oscillogram would seem to be a trustworthy indicator of the depositing mechanism.

This method, revealing as it does the mode of metal deposition, offers also a means for testing and comparing the depositing performance or so-called "weldability" of various types of electrodes. The results of tests of this kind may be interpreted, moreover, both for hand and for automatic welding.

These results are for "bare," or very lightly coated electrodes. The modern heavily coated electrode, because of its chemical protection to the metal in the arc, can and does use a longer arc length, in fact, so long that the globules are unable to bridge the arc and to cause the current peaks and voltage zeros of "short arc" welding. Globules are believed, however, to be the chief form of transfer, also when the longer arc and coated electrode are used. This question could readily be decided by the use of the method described in this paper, using heavily coated electrodes.

The authors wish to thank for his assistance with the oscillograph Professor A. R. Miller, and for preparing the sketches Mr. J. Leland Myer.

Lead "Burning" or Welding

By ROBERT L. ZIEGFELD

+This paper will be presented at the Fall Meeting of the American Welding Society, in Buffalo, Oct. 4, 1932. Mr. Ziegfeld is connected with the Lead Industries Association.

AUTOGENOUS welding of lead, known to the trade as lead burning, is a process which has been developed through many centuries of use and grew to really large proportions with the general availability of modern commercial gases such as oxygen, hydrogen, acetylene and calorene under pressure in cylinders. Today it is becoming increasingly important because the fields in which it is most generally applied are growing. Despite this there has been little written on the subject, probably because as a trade it was largely handed down from father to son, with instruction gained by personal contact and knowledge by personal experience.

The war, which caused great expansion of munitions and other chemical plants, caused lead burning to be more widely taught because of the dire need for lead burners in these plants, and it is now taught in some trade schools.

Lead welding may be considered to have originated in a crude fashion with the ancient pipe-makers of Rome or even earlier. These pipes were made by forming cast

sheet lead around a mandrel and pouring lead, at a temperature considerably above its melting point, along the horizontal seam to close it. They used the same method to join sections of lead pipe. While this actually formed a fusion weld, it was limited to work on the flat only.

It has been claimed that most of the lead work of the Middle Ages, which was very extensive, particularly for architectural purposes, was joined by ordinary soft solder, yet many of the numerous pieces of this work still in existence have been examined and are apparently welded. Another bit of evidence to support the theory that lead welding was used some time before it is generally accredited is that lead was used in commercial sulphuric acid plants as early as 1746. As sulphuric acid would have caused rapid failure of soldered seams in these plants, the chances are that they were made by welding. How it was done no one seems to know, but it was probably with the aid of an ordinary mouth blow-pipe. It must have taken infinite pains and considerable time, as we measure these things today.

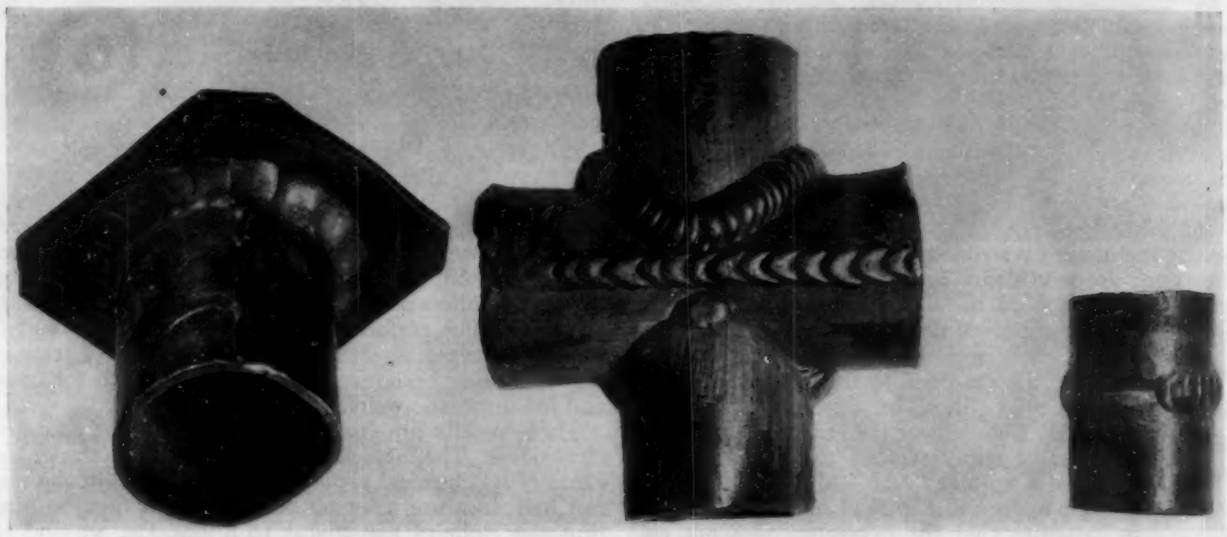
Flame burning, using manufactured gas, is believed to have been introduced in about 1837 when a French chemist, de Richemont, invented an aero-hydrogen blowpipe, the hydrogen being generated by the action of sulphuric acid on zinc. The hydrogen generators themselves had to be lead-lined to resist corrosion by the acid. About 1895 coal gas, which was handy and cheap in most shops, was combined with air to produce a blow-pipe flame, but 1905 brought the oxy-hydrogen flame which gave lead welding great impetus. This was when hydrogen became available in cylinders under pressure. It was the oxy-hydrogen method of lead burning that played such an important part in the war. Air-acetylene flames made their appearance after the war, but were limited to flat work and never became of great importance. However, they gave rise to the oxyacetylene method which is of considerable importance now.

Although there is some claim that oxy-hydrogen flames cause greater volatilization of lead than other types of flames, and that the hotter flames of other gases do better work, the vast majority of expert lead burners prefer oxy-hydrogen and claim that they can use it with greater success. It is used with mixtures varying from 4 parts of hydrogen and 1 of oxygen to equal parts of each on heavy work.

Lead burning is a true autogenous welding process, differing from the welding of other metals in that the melting point of lead is low (621° F. and 327° C.). This means that the operation is considerably more delicate than other welding because care must be taken not to burn through the lead. Very small torches with extremely fine tips are used because a very hot flame is not necessary. To permit rapid manipulation of the torch, lead burners usually separate the tip from the mixing valves by a length of hose. Mixing valves can then be set down and only the tip manipulated.

Lead joints should be made in a horizontal position and lapped whenever possible. Laps of $^1/_2$ in. to 1 in. are generally used. The lead is scraped clean with a shave-hook along the edges and back from the edges about an inch on both sides. This removes dirt and the coating of oxide that always forms on the surface of lead. Cleaning is particularly important in repair work. After the edges are cleaned and in position it is well to tap the upper sheet lightly with a wooden mallet to assure intimate contact between the sheets. Using a filler bar, the seam is then welded. Very light lead does not require a bar, but the weights, generally used commercially, do.

The flame is held approximately at right angles to the work, with the lead at about the tip of the inner cone. The two lead surfaces and the bar are brought just to the fusion point simultaneously and then the flame is rapidly flicked away by a quick movement of the wrist. This allows the lead to fuse together in a homogeneous mass, but prevents excessive melting. As this joint solidifies, flame and bar are applied at an adjacent point and the operation repeated until the entire seam is complete. When finished, welded seams in lead have a typical herringbone appearance that is as regular as though done mechanically, if the work is good.



A *B* *C*

Fig. 1

A—Lead pipe made from sheet lead by welding and flange attached by welding. Often used where lead pipe penetrates lead tank linings
B—Cross in lead pipe partly welded, showing complicated structures that can be made with aid of welding
C—Ordinary welded joint in lead pipe, partly made. Note beveled ends of pipe
In both *B* and *C* note where pipe has been scraped clean with shave-hook

Fig. 2—Welding a Flat Seam in Sheet Lead. Note position of filler bar and torch, and remote location of valves

Butt welds are made in about the same way, the sheets being placed abutting and tacked in position with the flame. Ordinary weights and heavy sheets are beveled along the edge so that they make an angle of about 30 deg. with each other.

Horizontal seams on vertical surfaces are made by lapping the lower sheet over the upper, the edge of the lower sheet thus preventing the melted lead from running away. Vertical seams are different in procedure. No filler bar is used and seams must be lapped, except in rare instances when butt welds may be made with the aid of a mold on handles manipulated by a helper. The lead is prepared in the same way as for horizontal seams but often has to be held in position by wooden forms while burning progresses. Welding starts at the bottom, the flame being applied to the top sheet until its edge is molten. This molten lead is guided by the flame down onto the under sheet and fused with it, the flame being flicked away before the under sheet is burned through. A shave-hook held just below the working point may help to cool the lead in place. Vertical seams in lead have the appearance of a rope when completed. Even smaller tips are used on vertical seams than on horizontal seams.

Overhead seams should be avoided. They can be made only by especially skilled workmen and can never be made as strong as flat or vertical seams. When they must be made they are lapped and made without filler bar. On all lead burning on which filler bars are used, the bar should have exactly the same composition as the lead; that is, if the sheets are chemical lead, burning bar should be chemical lead; if antimonial lead containing 6 per cent antimony, the bar should also contain 6 per cent antimony. Crawlproof lead, which is chemical lead reinforced with bars of antimonial lead imbedded in it, is welded with the aid of a chemical lead filler bar, the weld being built up a little higher than usual to assure sufficient thickness of chemical lead over the reinforcing bars.

Leadworkers have several commercial grades of lead at their disposal and it is well to know the properties of each so that the correct grade may be selected for a given job. Most flexible is common lead (desilverized or soft Missouri) but it is also the weakest. It should be used where easy bending and working is at a premium. Chemical lead, which derives its name from its wide use in the chemical industries, is stronger, slightly less flexible and more resistant to corrosion than common lead. It differs from common lead in containing larger amounts of copper—0.4 to 0.08 per cent. Antimonial lead, whose antimony content may run from 1 to 13 per cent and is generally in the neighborhood of 6 to 7 per cent, has nearly double the strength and is much more stiff and rigid than either of the other grades. As a rule it is not quite as resistant to corrosion as chemical lead, but in some cases, as when it is in contact with salt water, it seems to be more resistant. Crawlproof lead is still another possibility where both strength and corrosion resistance are important.

Welding of lead pipe is done the same as butt welds in sheet lead, the joint is made on the flat. When it is impossible to do this or to get at the underside of the pipe, it may be slit open on top, back from the ends and the upper walls of the pipe bent back. The lower half of the weld can then be made from the inside, the upper walls bent back into place, and the top of the joint and the slits burned from the outside. Pipe joints may also be welded by flanging one end of the pipe and fitting the other end into the flare.

It may be necessary, in working with heavy lead, to burn over a seam several times to build it up to the proper thickness and assure a strong joint. Welds should be built up a little higher than the adjacent metal but it should be remembered that beyond a certain point adding lead does no good. In architectural or other work where seams must be as invisible as possible, they may be scraped down flush with the lead surfaces after the seam has been finished.

Filler bars may be made by casting lead into regular molds for the purpose or using a piece of angle iron for the mold. A bar about $^{3}/_{8}$ in. in diameter is generally satisfactory for most work, on which sheet lead weighs from 6 to 10 lb. per sq. ft. ($^{3}/_{32}$ to $^{5}/_{32}$ in. thick). About 1 ft. of bar is then required per foot of seam.

It can be seen from this brief description of the mechanics of lead welding that it should not be difficult for a workman to master its fundamentals in comparatively short order. In fact, a couple of weeks are all that are necessary to teach the average man to do a fair job. But because of the delicacy of the operation and because the nature of the uses of lead welding demand a perfect job the first time, it is not easy, except after continued practice and experience, for a workman to produce flawless work rapidly.

Perhaps the largest field of application of lead welding is in the industries producing and consuming chemicals. Chances are that this application will continue to grow at a rapid rate because almost all modern development is dependent upon chemicals in one way or another. Many of these chemicals are highly corrosive to ordinary

Fig. 3—Large Lead Pipe for Acid Handling Is Often Made from Sheet Lead and Welded

materials of construction, yet lead admirably resists corrosion by many of the most common. A few, in contact with which lead is commercially used, are sulphuric, phosphoric and hydrofluoric acids, common salt solutions, zinc chloride and ammonium sulphate. The extent to which these substances are used in industry gives some idea of the extent to which lead is used in handling them, and welded joints are used almost exclusively because solder would be attacked and destroyed, and also because solder melts at lower temperatures than lead and would fail where processes required even small amounts of heat.

Storage and process tank linings are therefore often lead with welded seams. These linings may be loose linings, simply hung from the top of the tanks. They may be supported linings, with steel strips, running either horizontally or vertically, fastened to the tank shell through the lead and thus supporting it. Strips of lead are then placed over the steel strips and burned to the lead lining so that nothing but lead is exposed. Or still another possibility is homogeneous linings where the lead is actually bonded to the steel. This bonding may also be done by burning. The steel is first carefully cleaned, and fluxed with zinc chloride solution. Lead is then flowed onto the steel with the aid of a lead burners' torch, and becomes firmly attached to the steel.

Of course, much chemical equipment is entirely fabricated of lead, particularly antimonial or hard lead, and here again joints, when necessary, are burned. This would include not only pumps and valves, but also funnels, carboys and many other pieces of equipment. Heating coils are very frequently used in chemical tanks such as plating tanks. They may be made of coiled lead

Fig. 4—Hard Lead Cresting, Shedd Aquarium, Chicago. Joints Welded and Scraped

pipe either with pieces of lead burned between each turn as spacers, or with lead pipe legs running from top to bottom of the coil with notches cut out for each turn, and burned in place. Even floors in chemical plants are sometimes entirely covered with lead to prevent sparking and attack by corrosives, and seams are welded.

When lead pipe is used to transport corrosives, joints in it are also burned. Here is a big field because lead pipe is so generally used to handle salt water, an extremely common corrosive. This is not only true in hotels, seashore residences, industrial plants and aquariums, but on shipboard as well. The finest and newest ships being built in this country have all lead soil piping systems with burned joints, which is a new development with shipbuilders here. Such a system gives maximum corrosion resistance with flexibility that can stand the buffeting a ship must take. There may be said to be no joints in such a piping system, for after burning it is one continuous piece of lead pipe. Burned joints require less space than wiped joints and space is at a premium on shipboard. Because there are so many obstructions to pipe lines on ships, lead has an advantage over rigid pipes because easy bends can be made without joints or special fittings.

Because handling corrosives is such an important part of lead's work where welded joints are concerned, is the reason for the statement made earlier that welds in lead must be 100 per cent right the first time. Much lead welding is repair or patching; even on new work it is most often done in the field under far from ideal working conditions; as soon as the burning is completed, tanks, pipes or whatever the equipment may be are filled with highly corrosive, often dangerous, chemicals. Imperfections in welds would be disastrous, yet there is little opportunity for inspection. For that reason, in the chemical field in particular, lead burners must know how to do perfect jobs with rapidity. That only comes after much practice and experience.

X-ray room linings also require extensive lead welding, and this is another use for the process that is growing rapidly. Not only are X-rays much more generally used now than ever before in the medical and dental professions, but industry is taking them up in a big way as a means for searching for hidden flaws in materials and for other purposes. X-rays are extremely harmful to human beings unless confined to the locality at which they are required. Therefore rooms containing X-ray equipment should be completely, or under certain conditions, partially lined with sheet lead, the only effective, practical material for X-ray insulation. As the rays will penetrate other materials or the slightest openings, burned seams are used on these linings unless certain special types of construction are used. Even these generally require a considerable amount of shop burning.

Sheet lead is a very important waterproofing material. It is used in bathrooms, swimming and garden pools, conservatories, fountains and many special places. In these cases either soldered or welded seams are used, but those that are welded are many and probably give the best assurance of trouble-free service.

Recent revival of interest in this country in architectural lead work, such as is so extensively used abroad, has also opened up another fruitful field for lead welding. Much of this work requires no burning or soldering at all, loose-locked seams being used for roofing and flashing to allow for expansion and contraction. But ornamental lead work, crestings, finials, sometimes spandrels and other decorations do require welding, because solder is less durable and because solder would be brighter than the surrounding metal and makes seams prominent. It is in this type of work that welded seams are scraped down flush with adjoining metal for the sake of appearance, and because strength is not generally an important factor. The fabrication of hand-wrought lead work such as leader heads, flower boxes, humidors and other devices also requires lead welding to give unobtrusive, durable and moisture-proof joints.

Anti-vibration pads, used under building and machinery foundations, are often made of two sheets of lead enclosing two layers of asbestos. The lead completely envelopes the asbestos and must protect it from moisture. Seams in the lead are generally welded for permanence. This is another rapidly expanding use.

Lead welding is an important process in the storage battery industry for welding plate connectors and terminals. Among storage battery manufacturers all this work is done in the factory and is consequently simpler than that done in the field. It makes it possible to use oxygen-city gas flames, which are inexpensive but require slightly larger tips than other lead burning work. Some of the largest manufacturers have also found it

advantageous to do the work mechanically, passing the parts on an endless belt conveyor underneath three or four flames of different temperature which are permanently fixed. Battery repair shops as a general rule also use oxygen-city gas flames but, of course, cannot do their work mechanically.

One might go on almost ad infinitum describing the less important uses of lead burning. The interesting thing to note is that almost every use of lead welding is an expanding one—either the industry itself growing, as in the chemical industry, or the use of lead in the industry increasing, as in the case of architectural work.

The author wishes to acknowledge the valuable assistance of Mr. Walter H. Simonson, President, American Lead Burning Corporation, in the preparation of this paper.

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(*Continued from page 4*)

ERNEST LUNN, author of the paper on "Pre-Qualification Tests for Welders," graduated from the University of Michigan with Degree B.S. (E.E.). Member of Executive Committee of the AMERICAN WELDING SOCIETY and Past-Chairman of Chicago Section. Was Chairman of the Committee on "Qualification Tests for Welders." Became interested in welding in 1925 while Electrical Engineer of the Pullman Company. Made an extensive study of the subject in all its branches, both from a practical and theoretical standpoint. Developed several new methods particularly in the resistance welding and in the cast iron welding fields. Took an active part in the preparation of a group of welded specimens for the Bureau of Welding during that organization's study of weld characteristics. During the past two years has been engaged in consulting work.

W. A. MADDOX, co-author of the paper on "Influence of a Magnetic Field Parallel to the Iron Arc on Welding," took the Cooperative Course in Engineering at Georgia School of Technology, graduating in 1927. In January 1928 he entered the Student Course of the Westinghouse Electric & Manufacturing Co. He also attended the Westinghouse Welding School. Since September 1929 he has been Supervisor of automatic arc welding for the East Pittsburgh plants. Lately he has been working on the development of processes and methods of welding.

VINCENT P. MARRAN, author of the paper on "Qualification Requirements for Welders," was born in Sag Harbor, New York, the son of Captain Martin J. Marran, under whose tutelage he acquired a knowledge of the sea and marine engineering. On his graduation from High School he completed two courses at Pratt Institute, Brooklyn, New York, after which he became associated with the Western Electric Co. at Hawthorne, Ill., where he spent some time in the experimental department. In 1911 he came to the Walsh Holyoke Steam Boiler Works, Inc., at Holyoke, Mass., and in 1912 started their electric welding department. He has had supervisicn over the activities of the Electric Welding Department since that time. He is at present Vice-President in charge of Sales, and Chief Engineer.

JOHN T. NORTON, author of the paper on "On the X-Ray Determination of Stresses in Welds," was born in Medford, Mass. Graduated from M. I. T. in 1918. From 1920–1926 he was Research Associate in the Department of Physics, M. I. T., from 1926–1929 Assistant Professor, Dept. of Physics and since 1930 Associate Professor in the Department of Mining and Metallurgy. He has specialized in technical and industrial problems of X-rays and in problems of the physics of metals.

A. VOGEL, discussor of Ernest Lunn's paper, graduated from Massachusetts Institute of Technology in 1913, with the degree of Bachelor of Science in Architecture. Building Engineer and Architect for the General Electric Company since 1917. Designed industrial plants and commercial buildings in the United States, Canada, Mexico, Cuba and other countries. Designed large plants for the electrical industry in the U. S. S. R. Written papers and lectured on industrial plants, natural illumination and design of welded structures. Lecturer on building construction and welding at Union College.

F. JEROME WHITNEY, JR., co-author of the paper on "Corrosion Fatigue Study of Welded Low-Carbon Steel," graduated in June 1930 with the degree of B.S. in E.E. from Lehigh University. Held a fellowship in the Metallurgy Department at Lehigh from June 1930 to July 1931. Returned to the University in September as a graduate student working under the direction of Prof. Wilbur E. Harvey on corrosion fatigue of welds. Graduated in June 1932, with an M.S. in Metallurgy.

CHRISTIAN A. WILLS, author of the paper on "Welded Rolled Steel Design for the Iron and Steel Industry," was engaged in the fabrication and erection of steel plate construction with Struthers-Wells Company and the Hammond Iron Works of Warren, Pa., and the Enterprise Boiler Works of Youngstown, Ohio, from 1897 to 1905. In 1905 he entered the employ of The William B. Pollock Company and, as General Foreman and later as General Superintendent, has had broad experience in the production and engineering of the Pollock Company's products which include all types of steel plate construction as well as equipment for the iron and steel industry. In 1928 he was appointed General Manager.

ROBERT LINDLEY ZIEGFELD, author of the paper on "Lead Burning or Welding," graduated in mining engineering from the Sheffield Scientific School of Yale University in 1925. After graduation, he was employed by the New Modderfontein Gold Mining Co., Ltd., Transvaal, South Africa, and the Oliver Iron Mining Co., Eveleth, Minn., in engineering capacities. He has been connected with the Lead Industries Association since shortly after its organization in 1928 as Assistant to the Secretary. He is the author and co-author of numerous Association publications, and has written many articles for the technical press on various phases of the uses of lead.

C. J. Holslag

Numerous friends of Mr. Holslag will be pleased to learn that he is recovering rapidly from an accident caused by a fall over a motorboat during his vacation on August 13.

TECHNICAL ASSISTANTS

The Philadelphia Technical Service Committee, by means of their JOB CONSULTATION SERVICE, are peculiarly fitted to secure for the employer "The right man for the right job."

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If you have any means for technically trained men, this committee will endeavor to fill them. Requirements will receive prompt and careful attention and will be kept confidential.

Obituary

Wm. A. Slack, President of the Torchweld Equipment Company, Chicago, Ill., died after a short illness at St. Joseph's Hospital, Chicago, on Tuesday, June 21st. Mr. Slack was born in Chicago in 1875, and with the exception of four years spent in Philadelphia and three years on the Pacific Coast, has been a resident of Chicago all his life. He started a successful sales career early in life and built up a wide acquaintance in the manufacturing and jobbing trade throughout the United States. He became associated with the oxyacetylene welding industry at its very beginning and was one of the organizers of the Torchweld Equipment Company when that company was formed in 1917. At that time he was secretary of the company, and a few years later was made president, which position he has held up until the time of his death.

In the oxyacetylene industry, Mr. Slack was widely known as a hard worker and a splendid friend. His interest in the welfare and progress of the industry was unfailing, with the result that he was constantly subjected to responsibilities and association work as an executive and as a member of many committees. His activities in such work were always characterized by the expression of high ideals in manufacturing and merchandising and warm friendliness toward all of his associates.

He was a member and director of the AMERICAN WELDING SOCIETY and one of the founders and directors of the Chicago Section of that society, Past-President and Director of the International Acetylene Association, and a member of the Compressed Gas Association. He belonged to the Columbia A. F. & A. M., York Chapter Columbian Commandery, the Medinah Shrine and B. P. O. E. He was a member of the Medinah Athletic Club and the Ridgemoor Country Club of Chicago, and the People's Church, Chicago. The welding industry has lost one of its outstanding active workers, and many of the individuals of the industry feel a distinct personal loss with the passing of Mr. Slack, whose genial and kindly friendship invariably reflected a sincere interest in the welfare and happiness of his fellowmen.

Mr. Slack is survived by a widow, Mrs. Alice B. Slack, and brother, Chas. C. Slack of Chicago.

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A-176. Graduate civil engineer; electric arc welder with experience in design of welded structures, desires work in field of welding engineering. Also two years' surveying and three years' production.

A-177. First-class acetylene welder desires position. Has had 17 years' experience on all metals and 9 years' aircraft welding experience. Can also do sheet metal work.

A-178. Electric and acetylene welder with 18 years' experience desires position. All-around mechanic.

A-179. Acetylene, electric and Thermit welder desires position. Several years' supervisory experience. Boiler, structural and job welding experience, also demonstrating and sales ability.

A-180. Acetylene and arc welder experienced on aluminum cast iron high-class work seeks position. Will go anywhere.

A-181. Licensed professional engineer desires position. Have served as assistant factory manager to The Pfaudler Company, manufacturers of welded tanks and pressure vessels. Work included design and welding of vessels. Have also served as superintendent of the New Haven Copper Company; chief engineer of the Edison Storage Battery Company and assistant superintendent of the Alcoa Works, The Aluminum Company of America. Graduated from Columbia College, 1912. Also have post-graduate degree.

A-182. Engineer desires position. Recently connected with aircraft company. Experienced in electrical design development and research work in the development of a highly successful line of portable spot welders for stainless steel.

A-183. Experienced welder desires position. Have been welding since 1916, also as demonstrator for the Quasi-Arc Company. Have experience in arc and acetylene welding of ferrous and non-ferrous metals and alloys. Application included boilers, tanks, pipe lines, restaurant equipment, ornamental work, ship construction and automotive repair. Have also been foreman. Can furnish complete references.

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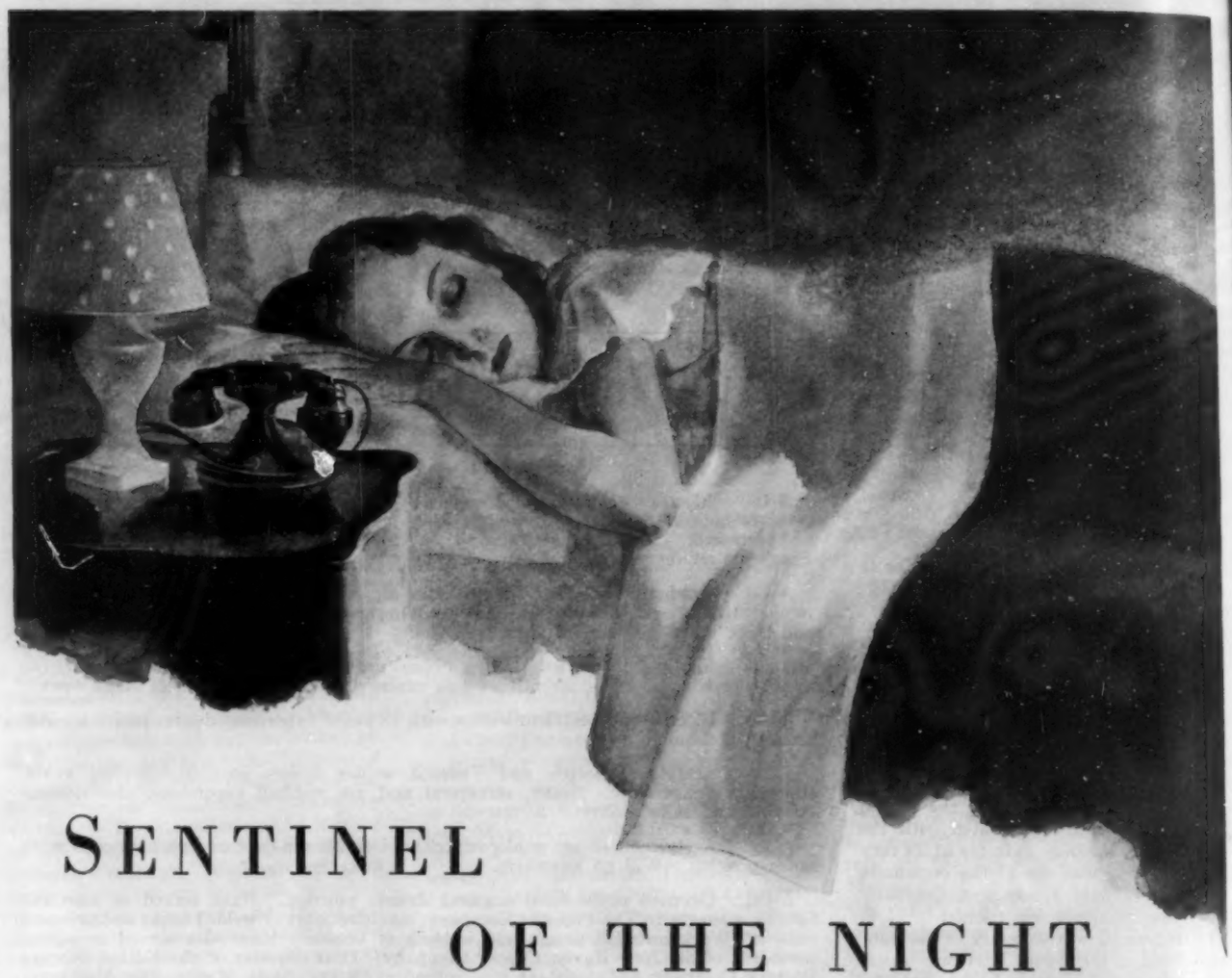

SENTINEL OF THE NIGHT

DEEP NIGHT . . . before the first grey streaks of dawn silver the eastern sky. On a table beside the bed rests a little black instrument . . . silent, unobtrusive, seemingly inert there in the stillness. It is the *telephone*, sentinel of the night.

Ready to call a policeman at the first unexplained sound . . . ready to summon the fire department at the first ominous whiff of smoke . . . primed to arouse a physician, a nurse, or a neighbor when illness intrudes.

For the wired world is at the other end, waiting for your outstretched hand and your plea: "Come quickly!"

Sentinel duty, of course, is a small part of the manifold service your telephone renders. The incidents of every-day store orders, of friendly chats; the joy and comfort of familiar voices as though from across the room; these, too, make the telephone a valued member of the family.

Behind your telephone is the nation-wide organization of trained minds and hands whose ideal is to serve you in a manner as nearly perfect as is humanly possible. Seven hundred thousand stockholders — men and women like yourself — have invested their money in this system of the people and for the people.

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